(0.082 mole) of the alcohol with 3.0 ml of 85% phosphoric acid, using a 10-in. distillation column. The olefin distilled quickly at 140° bath temperature: 7.4 g (separated from water), 94% of theory. Fractionation in column A gave a cut, bp 102–105°, n^{24}D 1.4420, 3.4 g [lit.[23,24] bp 102.5–105.8°, n^{25}D 1.4430]; glpc analysis (10-ft Ucon Polar LB-55OX, 20% on Chromosorb W, 95°, 20 psi of helium) showed 93.6% of the olefin at 13.7 min and 6.4% of an impurity at 9.5 min. This impurity and another substance were concentrated in the forerun fraction.

Hydrogenation of 1,2-dimethyl-1-cyclopentane (5.0 g, 0.052 mole) using 0.5 g of 5% palladium on carbon in 25 ml of anhydrous ethanol at 47.6-psi hydrogen pressure in a Parr hydrogenation apparatus gave a 4.4-psi pressure drop (100%) in 0.5 hr at 22°. XIIa,b, bp 90° (745 mm), n^{24}D 1.4128, 3.1 g, separated from the filtered solution when diluted with water. Glpc (same conditions as above) showed XIIa at 7.0 min, 77%; XIIb at 9.3 min, 21%; and 1.9% of another compound at 6.0 min. An infrared spectrum was consistent. From literature values[25] for *trans*-, bp 91.9° (760 mm), n^{25}D 1.4068, and *cis*-1,2-dimethylcyclopentanes, bp 99.5° (760 mm), n^{25}D 1.4196, it is clear that XIIa is the *trans* and XIIb is the *cis* isomer.

XIIa,b from Reduction of XIa,b.—XIa,b (1.0 g, 0.0045 mole; 27.2%; at XIa, 63.9% of XIb, 5.6% of X, and 4.1% of an isomeric compound), 10 ml of anhydrous ethanol, 2.0 g (0.03 g-atom) of zinc dust, and 1.0 ml of 55% aqueous hydriodic acid were heated in a bath at 67–72° under an efficient reflux condenser. Additions of 1 ml of 55% hydriodic acid were made after 5 min and 1 hr. After 2 hr the liquid was decanted into a separatory funnel, water (25 ml) was added, and the layer of XIIa,b separated, 0.35 g, 80%. The aqueous layer was extracted three times with dichloromethane. Glpc analysis of the dried hydrocarbon layer gave peaks at 6.0 min, 0.78%; XIIa at 7.0 min, 27.4%; at 8.2 min, 3.67%; and XIIb at 9.5 min, 68%; in good agreement with the original composition of isomers. The retention times of the two main components were identical with those of XIIa,b prepared above. The dichloromethane extract combined with the hydrocarbon layer gave a glpc analysis showing 29.8% XIIa and 72.3% XIIb. From these data the original mixture was 27.2% *trans*- and 63.9% *cis*-1-iodomethyl-2-methylcyclopentanes.

Free-Radical Addition of 1-Iodoperfluoropropane to 1,6-Heptadiyne.—1-Iodoperfluoropropane (29.6 g, 0.10 mole), ABN (0.32 g, 0.0020 mole), and 1,6-heptadiyne (18.4 g, 0.20 mole) were sealed in a heavy-walled glass tube which had been filled with nitrogen and evacuated three times at −78°. The tube was heated at 71° for 22 hr in an oil bath. The contents were distilled in column B. 1-Iodoperfluoropropane (10.6 g, 36% recovery), 1,6-heptadiyne (14.1 g, 76% recovery), XIIIa,b, in 82:12 ratio (bp 78–82° (10 mm), n^{25}D 1.4250–1.4305, 14.9 g, a 44% conversion), a cut (bp 70–72° (2.0–2.5 mm), n^{24}D 1.4618, 3.2 g (probably a mixture of bisadducts)), and a residue of 3.5 g were obtained. Redistillation of the XIIIa,b mixture gave four fractions, bp 106–107° (37 mm), n^{22}D 1.4300. According to glpc analysis (6-ft Carbowax 1500 column, 150°, 30 psi of helium), the first cut was 97.7% pure XIIIa with a retention time of 9.2 min. The last cut contained 49% of this compound and 40.6% of a compound with a retention time of 18.6 min. Its much greater retention time in analogy to the products from 1,6-heptadiene suggested that the latter might be a cylic isomer, and the substances were separated by preparative-scale glpc. Infrared spectra of the two compounds showed in both the C≡CH group (CH band at 3315 cm^{-1}, C≡C at 2120 cm^{-1}) and the CH═CI group (CH of the vinyl group at 3060 cm^{-1}). In the 9.2-min isomer XIIIa a strong band at 1632 (R_FCH═CI, *trans*) and bands at 985 and 920 cm^{-1} appeared. In the 18.6-min isomer XIIIb the R_FCH═CI band appeared at 1640, and the bands at 985 and 920 cm^{-1} were absent. This is therefore probably the *cis* isomer. Both gave the same elemental analysis.

Anal. Calcd for $C_{10}H_8F_7I$: C, 30.98; H, 2.08; F, 34.35. Found for XIIIa: C, 31.0; H, 2.26; F, 34.57. Found for XIIIb: C, 30.90; H, 2.24.

Registry No.—II, 13389-25-8; III, 13389-26-9; IV, 13389-27-0; Va, 13389-28-1; Vb, 13389-29-2; VIa, 13389-30-5; VIb, 13389-31-6; VIIa, 13421-43-7; VIIb, 13389-32-7; VIII, 1070-27-5; IXa, 13389-34-9; IXb, 13389-35-0; X, 13389-36-1; XIa, 13389-37-2; XIb, 13389-38-3; XIIa, 822-50-4; XIIb, 1192-18-3; XIIIa, 13389-39-4; XIIIb, 13389-40-7; *n*-octane, 111-65-9; *cis*-2-octene, 7642-04-8; *trans*-2-octene, 13389-42-9; 1-methyl-2-vinylcyclopentane, 13389-43-0.

The Chloramine-Induced Oxidative Dimerization of Phenols[1]

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The addition of ethereal chloramine to molten phenols **1**–**6** at 120–130° resulted in the formation of oxidative coupling products. The mechanism of these transformations was investigated by varying the structure of the chloramine, by investigating the effects of solvent and added ferrous sulfate, and by performing various other pertinent experiments. The conclusion has been reached on the basis of the observed results that the chloramine-induced oxidative dimerization of these phenols probably proceeds by way of an unprecedented redox reaction involving the generation of aminium and phenoxy radicals.

The ability of phenols to undergo oxidation with a number of inorganic reagents (Ag_2O, PbO_2, MnO_2, $Pb(OAc)_4$, $K_3Fe(CN)_6$, etc.) and organic peroxides is well documented.[4–6] In fact, this propensity for oxidation has permitted the widespread use of phenols as antioxidants.[4–6] The above reagents possess in common the property that they react *via* radical processes to generate phenoxy radicals in the initial stages of the oxidation process. The ultimate fate of the phenoxy radicals generated in this manner is, in general, a function of their gross structure, the conditions of the reaction, and the nature of the oxidizing agent.

In our earlier studies, we have elaborated on the unusual ring expansions which result when hot solutions of sodio 2,6-disubstituted phenoxides in excess of the parent phenols are treated with ethereal chloramine.[7] Because of the fact that the phenols were considered relatively more readily accessible than the chloramine (especially since the excess phenol which was employed as solvent could be recovered almost

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[1] Support of this work by the National Science Foundation, Grant GP-2939, is gratefully acknowledged.

[2] Alfred P. Sloan Foundation Research Fellow.

[3] Sinclair Oil Fellow, 1965–1966; Esso Summer Fellow, 1964.

[4] V. V. Ershov, A. A. Volod'Kin, and G. N. Bogdanov, *Russ. Chem Rev.*, **32**, 75 (1963).

[5] A. I. Scott, *Quart. Rev.*, **19**, 1 (1965).

[6] H. Musso, *Angew. Chem.*, **75**, 965 (1963).

[7] Preceding paper: L. A. Paquette and W. C. Farley, *J. Am. Chem. Soc.*, **89**, 3595 (1967). L. A. Paquette, *ibid.*, **84**, 4987 (1962); **85**, 3288 (1963); *J. Org. Chem.*, **28**, 3590 (1963); *J. Am. Chem. Soc.*, **85**, 4053 (1963); **86**, 500, 4092, 4096 (1964); *J. Org. Chem.*, **29**, 3447 (1964).

TABLE I

PRODUCTS FROM THE CHLORAMINE-INDUCED OXIDATIVE COUPLING OF PHENOLS

Entry	Phenol	Conditions	Product(s)	Yield, %, based on Phenol recovered	Yield, %, based on Chloramine added
1	**1**	$ClNH_2$ added to **1** (solvent) at 120–130°	**7**	22	9
2	**2**	$ClNH_2$ added to **2** (solvent) at 130–145°	**8**	...	26
3	**3**	$ClNH_2$ added to **3** (solvent) at 120–130°	**9**	66	41.8
4	**3**	$ClNH_2$ added to **3** in refluxing cumene	**9**	32	...
5	**3**	$(C_2H_5)NCl$ added to **3** (solvent) at 120–130°	**9**	54	...
6	**3**	$(n\text{-}C_4H_9)_2NCl$ added to **3** (solvent) at 120–130°	**9**	59	...
			$(n\text{-}C_4H_9)_2NH$	...	47
7	**3**	$ClNH_2$ added to **3** (solvent) containing 0.5 molar equiv of $FeSO_4$	**9**	53	...
8	**4**	$ClNH_2$ added to **4** (solvent) at 120–130°	**10**	54	31
9	**4**	$ClNH_2$ added to large excess of **4** (solvent) at 120–130°	**10**	...	34
10	**4**	$ClNH_2$ added to **4** in refluxing 1-octene	**10**	29.4	...
11	**5**	$ClNH_2$ added to **5** (solvent) at 120–130°	**11**	12	8
12	**6**	$ClNH_2$ added to **5** (solvent) at 120–130°	**12**	23	19
			13	14	12
13	**6**	$ClNH_2$ added to large excess of **6** (solvent) at 120–130°	**13**	...	27.7
14	**6**	$ClNH_2$ added to **6** in refluxing 1-octene	**13**	...	30

CHART I

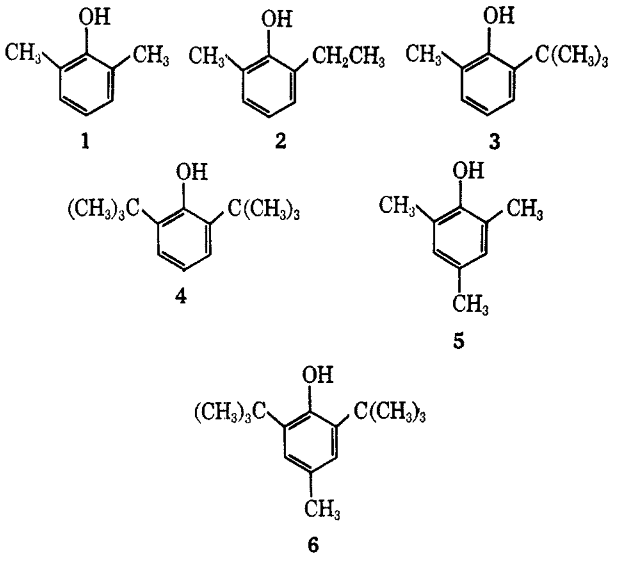
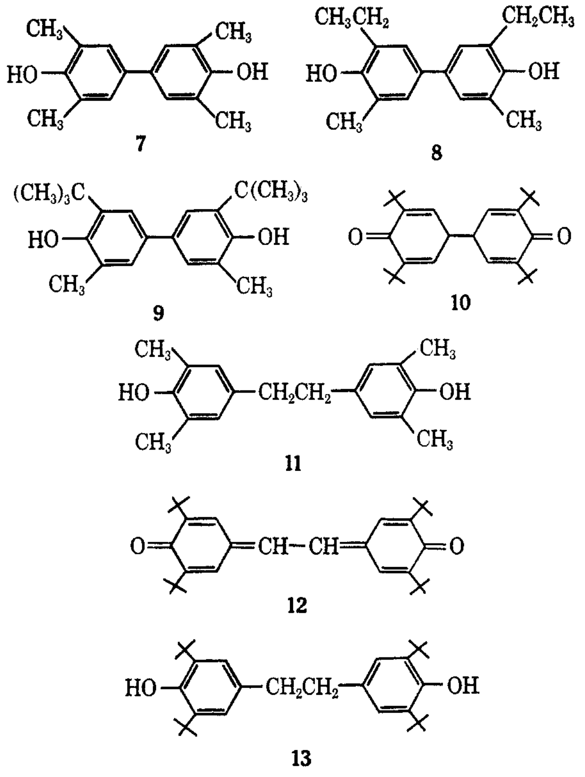


CHART II



quantitatively), these rearrangement reactions were always conducted in the presence of a slight excess of the sodium salt. Significantly, however, in one instance, when chloramine was added in excess to such a reaction mixture, the formation of products derived from the oxidative coupling of the phenol was observed. We wish in the present study to report on the details of this particular reaction and to elaborate upon the probable mechanistic course of this unusual process.

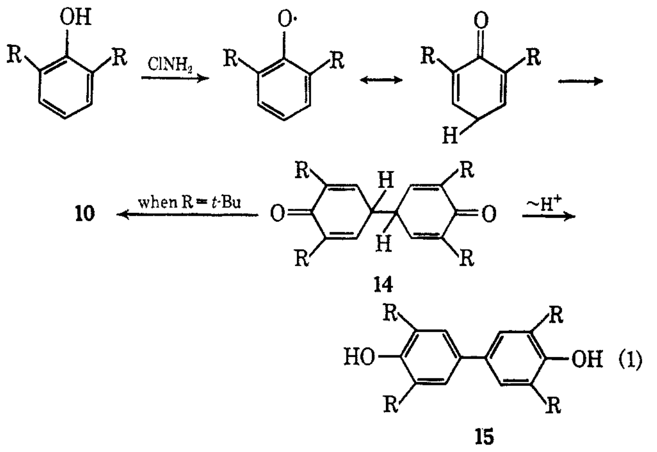
Results

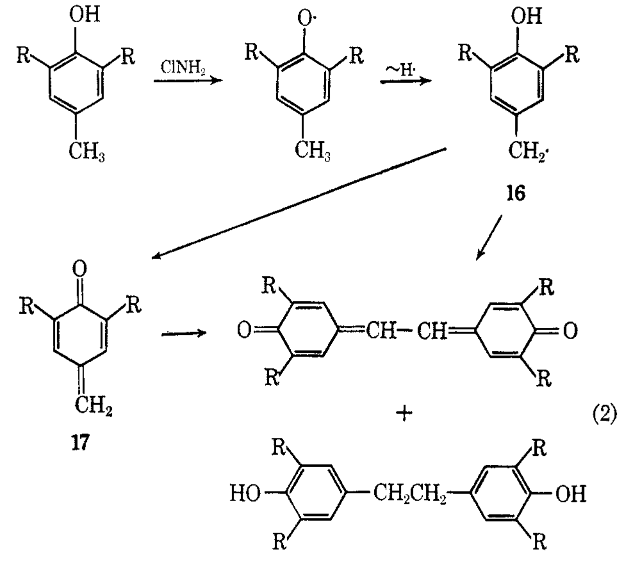
The six phenols (**1**–**6**, Chart I) employed in the present study were of the hindered variety because of the well-established ability of this type of substance to afford tractable products upon oxidation.[4-6]

Addition of a cold ethereal solution of chloramine to these molten phenols at 120–145° while stirring vigorously in a nitrogen atmosphere afforded the various oxidative coupling products **7**–**13** (Table I and Chart II). Confirmation of these structural assignments was achieved by comparison with authentic samples where possible, and by elemental and spectroscopic analysis as described in the Experimental Section. Because compounds **7**–**13** are of the type produced by a wide variety of oxidizing agents which invariably function as phenoxy radical formers, and, because such dimeric materials arise only when phenoxy radicals are generated (see eq 1 and 2), it may logically be concluded that the reaction of chloramine with phenols **1**–**6** at elevated temperatures is likewise proceeding *via* such reactive intermediates.

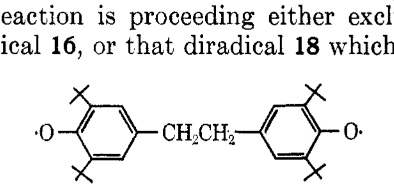
Of some significance is the observation that quinone **10** was the only product obtained in the oxidation of 2,6-di-*t*-butylphenol (**4**), even when the latter was present in large excess (entry 9, Table I). Apparently, either the rate of oxidation of the keto tautomer (**14**) of the biphenol is faster than the rate of prototropic shift to **15** under these reactions conditions, or **15** is more susceptible to oxidation than the monomeric phenol.

In the case of phenol **6**, the formation of stilbene quinone **12** and diphenylethane **13** (entry 12, Table) I can





be attributed to the intermediacy of rearranged benzyl radicals such as **16**,[8] or to the intervention of quinone methide **17** (eq 2).[9] However, when the reaction was performed in a large excess of **6**, the only product obtained was **13** (entry 13).[10] In this instance, it appears that the reaction is proceeding either exclusively *via* benzyl radical **16**, or that diradical **18** which can result



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from direct dimerization of quinone methide **17**[9b] abstracts hydrogen atoms from excess **6** at a rate faster than the rate of further oxidation by the chloramine. Furthermore, the oxidation of **13** is apparently discouraged in the presence of excess **6**.

Interestingly, the coupling reaction does not appear to be subject to steric retardation when the more hindered diethyl- and di-*n*-butylchloramines were employed. Thus, a comparative study of the effect of varying chloramine structure on the oxidation of **3** demonstrated that diphenol **9** was formed in roughly comparable yields in the three instances (entries 3, 5, and 6, Table I).

Function and Fate of the Chloramines.—With the demonstration that the above group of reactions proceeds *via* the corresponding phenoxy radicals, it remained to elucidate the function and fate of the chloramines. Several possibilities arise as a result of the observations made in the preceding section.

First, because of the relatively low energy of the N–Cl bond (47.7 kcal/mole),[11] one can entertain the possibility that the entire process is triggered by the initial formation of chlorine ($Cl\cdot$) and amino ($\cdot NH_2$) radicals. The ground and first excited states of the amino radical have previously been observed and found to have independent existence. Both species are nonlinear, the former having a σ-electron pair and a p vacancy and the latter possessing a σ vacancy and a p-electron pair.[14] Despite our knowledge of the intimate structure of the amino radical, however, a paucity of information surrounds its chemical behavior. The most recent experiments in this direction were reported by Neale and Hinman;[15] these workers found that strong irradiation of carbon tetrachloride solutions of chloramines containing butadiene failed to result in addition to the unsaturated substrate, in contrast to the smooth addition which occurs with aminium radicals ($R_2\dot{N}H^+$). The conclusion was reached that either the neutral amino radical did not form, or it did not add to the diene.[15] Despite the existing ambiguity concerning the chemical properties of $\cdot NH_2$, we were led to believe that, if homolysis of the N–Cl bond of chloramine were occurring, cumene should act as an effective radical trap on the basis of its ready reaction with radicals.[12,13] However, addition of chloramine to refluxing cumene *alone*, or in the presence of moderate concentrations of **3**, did not result in reaction with cumene. In the latter experiment (entry 4, Table I), biphenol **9** was formed as usual,[16] but no dicumyl was detected.[17] In view of the fact that the reflux temperature of cumene (153°) lies somewhat above the temperatures customarily employed in this study (120–130°), it may be reasonably expected that thermally induced homolysis of the N–Cl linkage should occur in pure cumene, if it were occurring at all, and that attack of the chlorine and amino radicals at the tertiary benzylic hydrogen of the aromatic hydrocarbon should result. The absence of such phenomena suggests that free chloramine is unable to

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[8] (a) C. D. Cook and B. E. Norcross, *J. Am. Chem. Soc.*, **81**, 1176 (1959); **78**, 3797 (1956). (b) C. D. Cook, N. G. Nash, and H. R. Flannagan, *ibid.*, **77**, 1783 (1955).

[9] (a) R. H. Bauer and G. M. Coppinger, *Tetrahedron*, **19**, 1201 (1963); (b) N. P. Neureiter, *J. Org. Chem.*, **28**, 3486 (1963); (c) B. R. Loy, *ibid.*, **31**, 2386 (1966); (d) L. J. Filar and S. Winstein, *Tetrahedron Letters*, No. 25, 9 (1960).

[10] The formation of stilbene quinone **12** is not likely to go undetected because of its very limited solubility.

[11] This value compares favorably with the strength of the O–Cl linkage (48.5 kcal/mole) [L. Pauling, "The Nature of the Chemical Bond," Third ed, Cornell University Press, Ithaca, N. Y., 1960, p 85], a bond whose propensity for homolytic fission has been examined in considerable detail.[12,13]

[12] C. Walling, "Free Radicals in Solution," John Wiley and Sons, Inc., New York, N. Y., 1957.

[13] W. A. Pryor, "Free Radicals," McGraw-Hill Book Co., Inc., New York, N. Y., 1966.

[14] D. A. Ramsay, *Ann. N. Y. Acad. Sci.*, **67**, 485 (1957); P. C. Jordan and H. C. Longuet-Higgins, *Mol. Phys.*, **5**, 121 (1962).

[15] R. S. Neale and R. L. Hinman, *J. Am. Chem. Soc.*, **85**, 2666 (1963).

[16] We attribute the somewhat lower yield in this run to a dilution effect which permits flash evaporation of the chloramine from the hot cumene solution prior to an opportunity for possible reaction with the phenol.

[17] Since phenols are effective at inhibiting the autoxidation of cumene [R. F. Moore and W. A. Waters, *J. Chem. Soc.*, 243 (1954)], it is doubtful that the cumyl radical would be formed in the presence of **3**. However, this reaction (entry 4) was performed in order to demonstrate that the oxidative coupling could proceed in this medium.

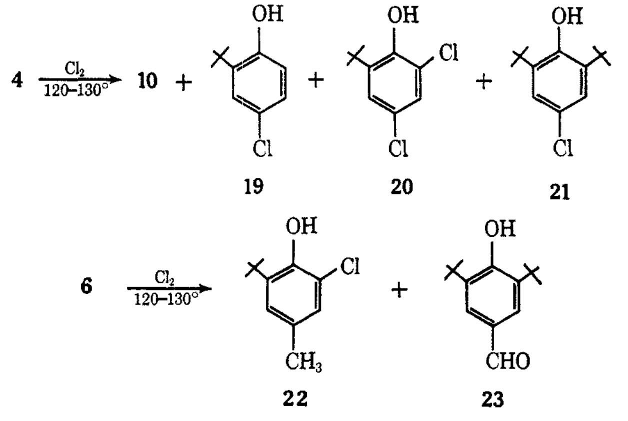
dissociate simply into radicals at the indicated temperatures.[18]

A second consideration concerned the possibility that small quantities of hydrogen chloride were being produced during the preliminary interaction with the phenols. Were this the case, rapid reaction by the hydrogen chloride with chloramine would be expected[19] to generate elemental chlorine (eq 3), which could act

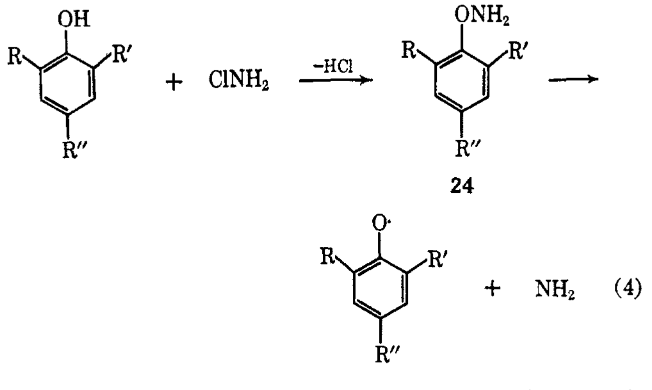
$$NH_2Cl + HCl \longrightarrow NH_3 + Cl_2 \qquad (3)$$

as the source of radicals (*i.e.*, Cl·) for the oxidative coupling. The foregoing hypothesis was removed from consideration on the basis of the expectancy that the chlorine generated in this manner would add, at least in part, to an olefin if present in considerable excess and that a discrete amount of electrophilic aromatic chlorination should also result when 2,6-disubstituted phenols are utilized. In actual fact, addition of ethereal chloramine to a dilute refluxing (125°) 1-octene solution of **4** and **6** resulted in the production of **10** and **13**, respectively, in good yield, but no 1,2-dichlorooctane was formed in either instance (entries 10 and 14, Table I).[20] Moreover, the dimerization process appeared not to be impeded. In addition, careful scrutiny, by vapor phase chromatography (vpc), of the nondimeric fractions in entries 1–10 failed to reveal the presence of halogenated phenols. That chlorinated phenols can be expected under conditions where chlorine is present was determined by adding cold ethereal chlorine to excess hot (120–130°) **4** and **6** in a manner comparable with that employed earlier. The results are displayed in Chart III and details are given in the Experimental Section. The foregoing data are taken to imply that chlorine is not involved in the genesis of the oxidation products.

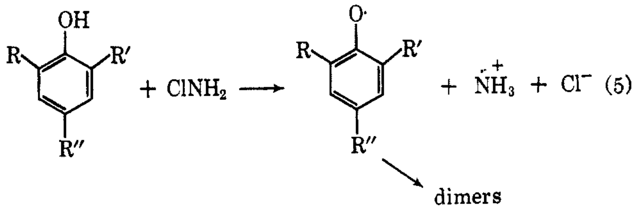
CHART III



The initial formation of O-arylhydroxylamines cannot be considered a realistic possibility (*i.e.*, eq 4). O-Phenylhydroxylamine has recently been prepared[21] and, although subject to resinification upon standing in air, this material can be distilled in an inert atmosphere. Furthermore, the efficiency of a condensation leading to an intermediate such as **24** can be expected to diminish with increasing steric bulk of the *o* substituents, but such is not observed.



However, the above facts appear to be consonant with the mechanistic pathway shown in eq 5. This scheme proposes initial proton transfer from phenol to chloramine followed by an unprecedented redox reaction to give phenoxy and aminium radicals and chloride ion. The suggested proton transfer is derived from several investigations of the kinetics of phenol chlorination by diethylchloramine and N-chloromorpholine;[22] the observed kinetic behavior was interpreted on the basis of an initial reaction which produced protonated dialkylchlorammonium ions. Aminium radicals are well recognized as the key intermediates generated by the irradiation or thermolysis of protonated chloramines in the synthetically useful Hofmann–Loeffler rearrangement.[23] The available evidence indicates that aminium radicals are capable of undergoing at least two types of chemical reactions, namely, hydrogen abstraction[23,24] and addition to olefins.[15,25] The hydrogen abstraction process has been most thoroughly examined under conditions where intramolecular homolytic C–H bond rupture could occur, presumably *via* cyclic transition states.[23] It is interesting to note, however, that aminium radicals are apparently not so reactive as most radicals toward intermolecular C–H radical abstraction; in fact, in the presence of suitable olefins, aminium radicals add preferably to the π bond rather than undergo intermolecular hydrogen abstraction from carbon.[25a,b]



In the oxidative coupling of phenols, the intermediate aminium ions, if formed, would be generated in the presence of excess phenol; as a consequence, the preferred reaction of these intermediates can be expected to

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[18] This view is reinforced further by our earlier observations that effective S_N2 displacement on the chloramine by ambident phenoxide ions occurs in the 130–150° range.[7] If homolysis of the chloramine N–Cl bond were occurring, these bimolecular reactions could not be realized.

[19] G. H. Coleman and W. A. Noyes, *J. Am. Chem. Soc.*, **43**, 2211 (1921).

[20] It was observed in a separate experiment that the addition of chlorine to 1-octene under similar conditions readily gave rise to 1,2-dichlorooctane.

[21] C. L. Bumgardner and R. L. Lilly, *Chem. Ind.* (London), 559 (1962); J. S. Nicholson and D. A. Peek, *ibid.*, 1294 (1962).

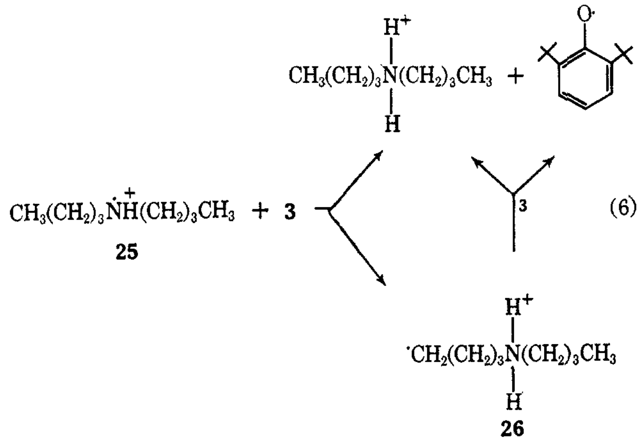
[22] L. O. Brown and F. G. Soper, *J. Chem. Soc.*, 3576 (1953); M. D. Carr and B. D. England, *Proc. Chem. Soc.*, 350 (1958).

[23] (a) M. E. Wolff, *Chem. Rev.*, **63**, 55 (1963); (b) R. S. Neale and M. R. Walsh, *J. Am. Chem. Soc.*, **87**, 1255 (1965); (c) R. S. Neale, M. R. Walsh, and N. L. Marcus, *J. Org. Chem.*, **30**, 3683 (1965).

[24] F. Minisci and R. Galli, *Tetrahedron Letters*, 2531 (1966).

[25] (a) R. S. Neale, *J. Am. Chem. Soc.*, **86**, 5340 (1964); (b) R. S. Neale, *Tetrahedron Letters*, 483 (1966); (c) F. Minisci and R. Galli, *ibid.*, 167 (1964); *Chem. Ind.* (Milan), **46**, 546 (1964), and earlier references cited therein; (d) F. Minisci and R. Galli, *Tetrahedron Letters*, 1679 (1965); (e) F. Minisci, R. Galli, and M. Cecere, *ibid.*, 3163 (1966); (f) C. J. Albisetti, D. D. Coffman, F. W. Hoover, E. L. Jenner, and W. E. Mochel, *J. Am. Chem. Soc.*, **81**, 1489 (1959).

be rapid (OH) hydrogen abstraction from the phenol (or, as in the case of **4**, also from the initially formed coupling product), a transformation which would lead directly to the corresponding ammonium chloride. However, the possibility of intramolecular hydrogen transfer in the particular case of **25** (see entry 6, Table I) to give **26** cannot be dismissed entirely because, if **26** did result to a significant extent, it likewise would be expected to abstract hydrogen rapidly from **3**, as shown in eq 6, to give rise to identical products. In actual fact, careful vpc analysis of the product resulting upon basification of the water-soluble residue in run 6 indicated the material to be virtually pure di-*n*-butylamine (47% yield). The rate of phenolic hydrogen abstraction by aminium radicals, if present, appears to be more rapid than addition to 1-octene under our conditions, as gauged by the observation that chloro amine formation was not observed in runs 10 and 14.



25

26

(6)

In one experiment (entry 7, Table I), ferrous sulfate was admixed with phenol **3** prior to addition of the chloramine. Ferrous ion is known to undergo a rapid redox reaction with chloramines[25d] and with hypochlorites.[12,13] The yield of **9** obtained in this experiment duplicated very closely the results observed in the absence of this inorganic salt. This result lends additional credence to the concept of aminium ion intervention.

Lastly, the possibility exists that oxidation of chloride ions by aminium radicals could eventuate in the formation of chlorine radicals as depicted in eq 7. Fortunately, information bearing on this question can be found in the existing literature. Thus, Albisetti and co-workers[25f] have demonstrated that chloride ions do not react with the aminium radical generated from hydroxylamine and titanium(III) chloride in acidic solution. In contrast, however, bromide ions are apparently oxidized to bromine radicals under these conditions. On the basis of their data, we discount the likelihood of this reaction in our study.[26]

$$\overset{+}{H\dot{N}}R_2 + Cl^- \longrightarrow H\ddot{N}R_2 + Cl\cdot \qquad (7)$$

Experimental Section[27]

General Procedure for the Chloramine-Induced Oxidative Dimerization of Phenols.—A 0.15-mole sample of the phenol was heated to 130° under a nitrogen atmosphere. With rapid stirring, a cold (−70°) ethereal solution of the chloroamine, containing approximately 0.18 mole of active reagent,[28] was added in a thin stream at a rate such that the internal temperature did not fall below 120°.[29] At the end of the addition, the reaction mixture was cooled and dissolved in ether or methylene chloride. The organic layer was washed with water, dried, and concentrated. The various products were separated by chromatography of the residue on Florisil. The properties of the various oxidation products are summarized below.

4,4′-Dihydroxy-3,3′,5,5′-tetramethylbiphenyl (**7**) was obtained as white needles from ethanol: mp 220–222° (lit.[17] mp 221°); $\nu_{max}^{CCl_4}$ 3675 cm^{-1} (OH stretching).

3,3′-Diethyl-4,4′-dihydroxy-5,5′-dimethylbiphenyl (**8**) was obtained as a pale yellow solid from ligroin: mp 144–145°; $\nu_{max}^{CCl_4}$ 3650 (OH stretching) and 1600 cm^{-1} (aromatic C–H stretching); $\delta_{TMS}^{CDCl_3}$ 1.30 (triplet, J = 8 cps, 6 H, CH_3CH_2), 2.30 (singlet, 6 H, aryl CH_3), 2.67 (quartet, J = 8 cps, 4 H, CH_3CH_2), 4.60 (singlet, 2 H, OH), and 7.16 (singlet, 4 H, aromatic protons).

Anal. Calcd for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20. Found: C, 79.70; H, 8.26.

3,3′-Di-*t*-butyl-4,4′-dihydroxy-5,5′-dimethylbiphenyl (**9**) was isolated as white crystals from hexane–benzene (9:1): mp 181–182°; $\nu_{max}^{CCl_4}$ 3560 cm^{-1} (OH stretching); $\delta_{TMS}^{CDCl_3}$ 1.48 [singlet, 18 H, $C(CH_3)_3$], 2.25 (singlet, 6 H, aryl CH_3), 4.73 (singlet, 2 H, OH), and 7.23 and 7.38 (doublets, J = 3 cps, 4 H, aromatic protons).

Anal. Calcd for $C_{22}H_{30}O_2$: C, 80.93; H, 9.26. Found: C, 80.93; H, 9.35.

3,5,3′,5′-Tetra-*t*-butyl-4,4′-diphenoquinone (**10**) was isolated as red-brown plates with a purple reflex from ethanol: mp 245–246° (lit.[30] mp 246°); $\nu_{max}^{CHCl_3}$ 1635 (C=O stretching) and 1605 cm^{-1} (vinyl C–H stretching).

4,4′-Dihydroxy-3,3′,5,5′-tetramethyldibenzyl (**11**) was obtained as white needles from ethanol: mp 164–166° (lit.[17] mp 168°); $\nu_{max}^{CCl_4}$ 3675 cm^{-1} (OH stretching).

3,5,3′,5′-Tetra-*t*-butylstilbene-4,4′-quinone (**12**) was characterized as red platelets from ethyl acetate: mp 314–315° (lit.[8b] 315–316°); $\delta_{TMS}^{CDCl_3}$ 1.41 and 1.48 [singlets, 18 H, $C(CH_3)_3$], 7.10 and 7.62 (doublets, J = 2.3 cps, 1 H each, vinyl protons), and 7.34 (singlet, 4 H, ring vinyl protons).

1,2-Bis-(3,5-di-*t*-butyl-4-hydroxyphenyl)ethane (**13**) was obtained as white needles from ethanol: mp 169–171° (lit.[8b] 170–171°); $\nu_{max}^{CHCl_3}$ 3700 cm^{-1} (OH stretching); $\delta_{TMS}^{CDCl_3}$ 1.42 [singlet, 18 H, $C(CH_3)_3$], 2.84 (singlet, 4 H, CH_2CH_2), 5.00 (singlet, 2 H, OH), and 6.98 (singlet, 4 H, aromatic protons).

Chlorination of 2,6-Di-*t*-butylphenol (4).—A cold (−70°) solution of 10 g (0.14 mole) of chlorine in approximately 100 ml of ether was added dropwise to 14.5 g (0.07 mole) of hot (120–130°) **4** with rapid stirring. After the addition, the reaction mixture was distilled under reduced pressure to give 4.8 g of a yellow oil, bp 100–112° (1 mm). Vpc analysis of this liquid (10 ft × 1/4 in. aluminum column packed with 20% SF-96 on Chromosorb W, 150°) indicated a four-component mixture consisting of 17% **19**, 7% **20**, and 23% **21**, the remainder (53%) being recovered **4**. The various components were separated by preparative vpc and were characterized as follows.

4-Chloro-2-*t*-butylphenol (**19**) was obtained as a pale yellow liquid: $\nu_{max}^{CCl_4}$ 3500 (OH stretching) and 1575 cm^{-1} (aromatic

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[26] A referee has suggested that these transformations can likewise be explained on a mechanistic level by means of the intermediate formation of a charge-transfer complex between the phenol and chloramine, with the phenol partner then transferring a hydride ion to $NH_2Cl\cdot^+$ to give either NH_3, Cl·, and ArO· or $NH_3\cdot^+$, Cl^-, and ArO·. This suggestion was advanced in order to bypass the necessity of requiring the aminium radical to abstract a (OH) hydrogen atom from the phenol. We believe that the hydrogen-abstraction step in question should not be prohibitive for the aminium radical and that formation of a charge-transfer complex at the elevated temperatures employed herein must be considered overly speculative.

[27] Melting points and boiling points are uncorrected. The microanalyses were determined by the Scandinavian Microanalytical Laboratory, Herlev, Denmark. The infrared spectra were obtained with a Perkin-Elmer Model 237 Infracord spectrometer fitted with sodium chloride prisms. Ultraviolet measurements were made with a Cary Model 14 recording spectrometer. The nmr spectra were determined with a Varian A-60 spectrometer purchased with funds made available from the National Science Foundation.

[28] NH_2Cl: G. H. Coleman and H. L. Johnson, *Inorganic Syntheses*, **1**, 59 (1939). Et_2NCl and $(n\text{-}Bu)_2NCl$: ref 23b.

[29] For practical reasons, the nitrogen flow over the surface of the phenol was stopped immediately prior to the addition of the ethereal chloramine. If this practice was not adopted, much chloramine was lost by flash evaporation and rapid removal from the reaction environment. The large expansion of vapors (predominantly ether) which takes place during the reaction precludes without doubt the diffusion of oxygen or air into the system. When the addition was completed, the slow passage of nitrogen into the flask was resumed.

[30] M. S. Kharasch and B. S. Joshi, *J. Org. Chem.*, **22**, 1439 (1957).

C═C stretching); $\delta_{TMS}^{CCl_4}$ 1.38 [singlet, 9 H, $C(CH_3)_3$], 5.79 (singlet, 1 H, OH), and *ca.* 7.0 (multiplet, 3 H, aromatic protons); lit.[31] bp 144–146° (26 mm).

2,4-Dichloro-6-*t*-butylphenol (**20**) was isolated as a pale yellow liquid: $\nu_{max}^{CCl_4}$ 3690 (OH stretching) and 1575 cm^{-1} (aromatic >C═C< stretching); $\delta_{TMS}^{CCl_4}$ 1.35 [singlet, 9 H, $C(CH_3)_3$], 5.80 (singlet, 1 H, OH), and 7.15 (singlet, 2 H, aromatic protons); lit.[32] bp 142° (22 mm).

2,6-Di-*t*-butyl-4-chlorophenol (**21**) was obtained as a white solid: mp 78–79° (lit.[33] mp 79.0–79.5°); $\nu_{max}^{CCl_4}$ 3775 (OH stretching) and 1575 cm^{-1} (aromatic >C═C< stretching); $\delta_{TMS}^{CDCl_3}$ 1.30 [singlet, 18 H, $C(CH_3)_3$], 5.01 (singlet, 1 H, OH), and 7.08 (singlet, 2 H, aromatic protons).

The residue from the above distillation was slurried in cold hexane and filtered to give 1.1 g (8%) of **10**, mp 245–246°.

Chlorination of 2,6-Di-*t*-butyl-4-methylphenol (**6**).—A 16-g (0.07 mole) sample of **6** was chlorinated with 10 g (0.14 mole) of chlorine as described above. Distillation of the reaction mixture afforded 5.3 g of a yellow crystalline distillate which was composed of 96% **6** and 4% **2-chloro-4-*t*-butyl-6-methylphenol** (**22**). Preparative vpc of the latter component gave a pale yellow oil with the following spectral properties: $\nu_{max}^{CCl_4}$ 3700 (OH stretching) and 1575 cm^{-1} (aromatic >C═C< stretching); $\delta_{TMS}^{CCl_4}$ 1.50 [singlet, 9 H, $C(CH_3)_3$], 2.24 (singlet, 3 H, aryl CH_3), 5.65 (singlet, 1 H, OH), and 6.98 (singlet, 2 H, aromatic protons); lit.[34] bp 105–106° (10 mm).

The residue from the distillation was slurried in cold ethanol and filtered. After recrystallization of the residue from ethanol, there was obtained 3.8 g (26%) of **23** as a pale yellow solid: mp 186–188° (lit.[35] mp 187–189°); $\nu_{max}^{CCl_4}$ 3600 (OH stretching), 1690 (C═O stretching), and 1575 cm^{-1} (aromatic >C═C< stretching); $\delta_{TMS}^{CDCl_3}$ 1.50 [singlet, 18 H, $C(CH_3)_3$], 5.88 (singlet, 1 H, OH), 7.81 (singlet, 2 H, aromatic protons), and 9.96 (singlet, 1 H, aldehydic proton).

Registry No.—**7**, 2417-04-1; **8**, 13395-83-0; **9**, 3432-00-6; **10**, 2455-14-3; **11**, 6476-26-2; **12**, 809-73-4; **13**, 1516-94-5; **19**, 13395-85-2; **20**, 13395-86-3; **21**, 4096-72-4; **22**, 13395-07-8; **23**, 1620-98-0.

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[31] G. Stork and W. N. White, *J. Am. Chem. Soc.*, **78**, 4604 (1956).

[32] A. J. Kolka, J. P. Napolitano, A. H. Filbey, and G. G. Ecke, *J. Org. Chem.*, **22**, 642 (1957).

[33] W. C. Sears and L. J. Kitchen, *J. Am. Chem. Soc.*, **71**, 4110 (1949).

[34] W. H. Starnes, Jr., *J. Org. Chem.*, **31**, 3164 (1966).

[35] G. R. Yoke, J. E. Dunbar, R. L. Pedrotti, F. M. Scheidt, R. G. H. Lee, and E. E. Smith, *ibid.*, **21**, 1289 (1956).

Oxocane. Synthesis and Conformational Isomerization[1]

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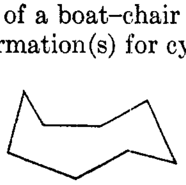
An unequivocal synthesis of oxocane, the cyclic eight-membered ring ether related to cyclooctane, is described. Low-temperature nmr analysis of the possible conformations and conformational processes available to this heterocyclic system suggested that the introduction of the oxygen atom served to facilitate ring-inversion processes, at least when compared to cyclooctane. These data permit the conclusion that strain minimization accompanies the introduction of an ether oxygen atom into a medium-sized ring.

For some years there has been keen interest in the conformational analysis of medium-sized rings.[3] Recently, attempts to analyze by means of temperature-dependent nmr spectroscopy the conformations and conformational processes occurring in cyclooctane and certain of its derivatives have been reported.[4] The conclusion has been reached[4b] that the evidence to date can best be interpreted in terms of the preferred existence of a boat–chair (**1**) and/or a twist boat–chair (**2**) conformation(s) for cyclooctane.



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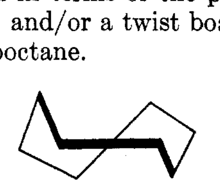

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At the same time, the interesting proposal has been advanced that the conformation of eight-membered rings can be expected to remain essentially unchanged when a methylene group is replaced by a heteroatom such as oxygen.[5,6] However, recent studies in this laboratory[7] have indicated that strain minimization accompanies the replacement of a CH_2 group by O in medium-sized rings. Further demonstration of the smaller steric requirements of ether oxygen relative to a methylene group has been found in the preferred axial orientation of the *t*-butyl group in *cis*-2-alkyl-5-*t*-butyl-1,3-dioxanes.[8] In view of these divergent considerations, we have deemed it of interest to prepare oxocane, the oxygen heterocycle related to cyclooctane, and to examine its temperature-dependent nmr behavior. The present paper presents the results of this investigation.

Synthesis.—Lithium aluminum hydride reduction of the known 9-methyl-3-oxagranatanin-7-one (**3**) gave a mixture of epimeric 9-methyl-3-oxagranatanin-7-ols (**4**) in quantitative yield. Dehydration of **4** with sulfuric acid in acetic acid[9] afforded 9-methyl-3-oxagranatoline (**5**) in 88% yield. The highly crystalline methiodide **6** formed rapidly upon addition of methyl iodide to **5** in ethanol solution (99% yield). Elution of **6** through Amberlite IRA-400 ion-exchange resin (basic form) served to generate the related methohydroxide. Controlled Hofmann elimination resulted in the liberation of water and the formation of 5-dimethylamino-7-oxa-

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[1] Unsaturated Heterocyclic Systems. XXVII. For XXVI, see L. A. Paquette and W. C. Farley, *J. Am. Chem. Soc.*, **89**, 3595 (1967). This work was supported in part by the Petroleum Research Fund, administered by the American Chemical Society. We express our appreciation to the donors of said fund.

[2] Alfred P. Sloan Foundation Research Fellow.

[3] For summaries of past work on this subject, see (a) E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," Interscience Publishers, Inc., New York, N. Y., 1965, Chapter 4; (b) M. Hanack, "Conformation Theory," Academic Press Inc., New York, N. Y., 1965.

[4] (a) J. D. Roberts, Abstracts of the 19th National Organic Symposium, Tempe, Ariz., June 1965; (b) F. A. L. Anet and M. St. Jacques, *J. Am. Chem. Soc.*, **88**, 2585 (1966); (c) F. A. L. Anet and M. St. Jacques, *ibid.*, **88**, 2586 (1966); (d) M. St. Jacques, M. A. Brown, and F. A. L. Anet, *Tetrahedron Letters*, 5947 (1966).

[5] See ref 3a, p 210.

[6] J. Dale, *J. Chem. Soc.*, 93 (1963); J. Dale, *Angew. Chem. Intern. Ed. Engl.*, **5**, 1000 (1966).

[7] L. A. Paquette and R. W. Begland, *J. Am. Chem. Soc.*, **88**, 4685 (1966).

[8] E. L. Eliel and M. C. Knoeber, *ibid.*, **88**, 5347 (1966).

[9] A. C. Cope and C. G. Overberger, *ibid.*, **70**, 1433 (1948).