88%) as a white solid: mp 186–187° (lit.[4] mp 186°); ir (KBr) 1700, 1280 cm^{-1}; pmr (CF_3CO_2H) δ 4.22 (s, 3 H, CH_3), 8.76–9.70 (m, 3 H, C_3H, C_4H, and C_6H).

Methyl Nicotinate-*6-*^{13}C. A suspension of 5-carbomethoxypyridine-2-carboxylic acid-*2-*^{13}C (2.05 g, 11.3 mmol) in anisole (50 ml) was refluxed for 6 hr. The anisole solution was concentrated to 5 ml by fractional distillation (at atmospheric pressure). This mixture was then distilled at 14 mm (bulb to bulb) at 100–140°, giving a clear, colorless solution of methyl nicotinate-*6-*^{13}C in anisole.

The distillation residue (0.25 g) was dissolved in methylene chloride and treated with excess diazomethane. The dimethyl pyridine-2,5-dicarboxylate thus obtained could successfully be recycled (hydrolysis and decarboxylation), yielding additional quantities of methyl nicotinate-*2-*^{13}C.

The spectral characteristics of the anisole solution of methyl nicotinate-*6-*^{13}C were ir (anisole) 1725 and 1120 cm^{-1}; pmr (anisole) δ 3.57 (s, 3 H, CH_3), 6.4–7.2 (m, anisole ring protons and C_5H), 7.95 (dddd, 1 H, $J_{2,4} = 2.2$, $J_{4,5} = 8.0$, $J_{4,6} = 1.8$, $^3J_{C,H} = 7.5$ Hz, C_4H), 8.47 (ddd, 1 H, $J_{4,6} = 1.8$, $J_{5,6} = 5.0$, $^1J_{C,H} = 180$ Hz), 9.14 (dd, 1 H, $^3J_{C,H} = 11.5$, $J_{2,4} = 2.2$ Hz, C_2H); cmr (anisole) 153.57 ppm.

Nicotinamide-*6-*^{13}C. The combined portions of methyl nicotinate in anisole were mixed with 150 ml of water and cooled in an ice bath. Ammonia was bubbled through the mixture for 6 hr at 3° and then for 12 hr at room temperature. Ether (50 ml) was added and the layers were separated. The etheral solution was extracted with water (25 ml). The combined aqueous portions were lyophilized, leaving 1.17 g (85%)[7] of a white solid: mp 128–130° (lit. mp 129.5–130.5°); ir (KBr) 3350, 3160, 1675, 1395 cm^{-1}; pmr (D_2O) δ 7.50 (m, 1 H, $^2J_{C,H} = 3.5$, $J_{4,5} = 8.2$, $J_{5,6} = 5.1$ Hz, C_5H), 8.13 (m, 1 H, $^3J_{C,H} = 7$, $J_{2,4} = 2.2$, $J_{4,6} = 1.8$, $J_{4,5} = 8.2$ Hz, C_4H), 8.61 (ddd, 1 H, $^1J_{C,H} = 182$, $J_{4,6} = 1.8$, $J_{5,6} = 5.1$ Hz, C_6H), 8.78 (dd, 1 H, $^3J_{C,H} = 11$, $J_{2,4} = 2.2$ Hz); cmr (D_2O) 152.64 ppm.

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Registry No.—**1**, 50790-51-7; **3**, 50790-52-8; **4**, 50790-53-9; **5**, 50790-54-0; **6**, 50790-55-1; **7**, 50790-56-2; *o*-aminobenzaldehyde, 529-23-7; acetone-*2-*^{13}C, 3881-06-9.

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(6) Other degradation and synthetic schemes investigated were complicated by the water solubility of the quinoline and pyridine acids which required special purification techniques such as copper salts, continuous extraction, etc.
(7) Based on per cent conversion of 5-carbomethoxypyridine-2-carboxylic acid-*2-*^{13}C.

Chlorination of Phenols with Chlorine and *tert*-Butyl Hypochlorite. A Comparison

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In 1971, a review was written by Pearson and Buehler[1] on unusual electrophilic aromatic substitution reactions. A section discusses ortho enhancement, which was defined as a reaction which produces more than 66.7% ortho substitution, the statistical percentage of this position. The review states that the first successful attempts in the ortho chlorination of phenols were accomplished by *tert*-butyl hypochlorite usually in ethanol and/or carbon tetrachloride. The review also states that solvent effects and temperature have a slight influence on the ortho/para ratio but not to the extent that one would choose these factors alone to control orientation.

The statement concerning *tert*-butyl hypochlorite is derived from the work of Clark[2,3] and Ginsburg.[4,5] Clark[2,3] reported that the *tert*-butyl hypochlorite chlorination of phenol in ethanol yields 92.3% 2-chlorophenol and 87.4% 2,4-dichlorophenol, while in carbon tetrachloride it yields 57% 2-chlorophenol. Ginsburg[4,5] reported that *tert*-butyl hypochlorite reacts with 2-chlorophenol in carbon tetrachloride to yield 73% 2,6-dichlorophenol, a result which is quoted in a text on aromatic halogenation,[6] but reacts with 2-methylphenol to yield only 31% 6-chloro-2-methylphenol. Ginsburg[5] implied that alkyl hypochlorites attack phenol by a free-radical mechanism.

In 1961, Harvey and Norman[7] investigated the chlorination of various aromatic compounds, including phenols, with chlorine and *tert*-butyl hypochlorite utilizing vpc for analysis. Chlorine chlorination of molten phenol yields 39.5% 2-chlorophenol and 60.5% 4-chlorophenol. These results have been substantiated by Bing[8] and Zee.[9] Chlorination of phenol with chlorine in carbon tetrachloride yielded 74.0% 2-chlorophenol and with *tert*-butyl hypochlorite 51.0% 2-chlorophenol. From these data they concluded that *tert*-butyl hypochlorite does not give rise to high ortho/para ratios in the chlorination of phenols. Based on their observations, Harvey and Norman also proposed and gave evidence that the reaction was ionic *via* the formation of chlorine rather than free radical.

Harvey and Norman, however, did not repeat the work of Clark[2] or Ginsburg.[4] All of these authors ran their reactions at various concentrations and temperatures. For example, Harvey and Norman[7] chlorinated a 5.3% solution of phenol in carbon tetrachloride with chlorine and a 13% solution of phenol in carbon tetrachloride with *tert*-butyl hypochlorite.

One of the purposes of this work is to reexamine the chlorination of phenol in ethanol with *tert*-butyl hypochlorite. Temperature and concentration effects on the chlorination of phenol in carbon tetrachloride with chlorine and *tert*-butyl hypochlorite will be reported. Finally the results of a direct comparison of the chlorination of three phenols (phenol, 2-methylphenol, and 2-chlorophenol) with chlorine and *tert*-butyl hypochlorite, maintaining a constant temperature and concentration, will be discussed.

Results and Discussion

The claim of Clark[2] that chlorination of phenol with *tert*-butyl hypochlorite in ethanol yields 92.3% 2-chlorophenol could not be reproduced. On the contrary, *tert*-butyl hypochlorite chlorination of a 10% solution of phenol in ethanol at 15° yields 30.3% 2-chlorophenol and 65.3% 4-chlorophenol for an ortho/para ratio of 0.46. Chlorination under the same conditions except that the solvent was 95% ethanol and 5% water gave essentially the same results; *i.e.*, the maximum yield of 2-chlorophenol is 29.4% and the ortho/para ratio is 0.45. However, the addition of 2 equiv of *tert*-butyl hypochlorite to a 10% solution of phenol in ethanol at 15° did yield 86.9% 2,4-dichlorophenol, in good agreement with the 87.4% yield reported by Clark.[2]

Ethanol has been reported by Campbell and Shields[10] to be one of the solvents that favor para substitution in the chlorine chlorination of 2-methylphenol. We confirmed this report by chlorinating a 10% solution of phe-

Table I
Chlorination of Phenol in Carbon Tetrachloride

Chlorinating agent	Concentration, wt %	Temp, °C	Maximum yield of 2-chlorophenol, wt, %	Ortho/para
Cl_2	Neat	60	29	0.65[a]
Cl_2	10	78	57.7	1.6
Cl_2	5	78	68.0	2.5
Cl_2	10	18	52.8	1.3
$(CH_3)_3COCl$	10	78	53.3	1.3
$(CH_3)_3COCl$	10	15	45.8	0.92
$(CH_3)_3COCl$	33	78	47.5	1.0

[a] Reference 8.

nol in refluxing ethanol and obtained a yield of 27.5% 2-chlorophenol and 56.0% 4-chlorophenol for an ortho/para ratio of 0.49.

In their study of solvents, Campbell and Shields[10] found that the isomer ratios obtained from the chlorine chlorination of a 25% solution of 2-methylphenol in the various solvents varied owing to the hydrogen bonding between the hydroxy group and the solvent. The bound solvent molecule exerts a steric effect on the ortho position and thus leaves the para position open to attack and consequently increases the yield of the 4-chloro isomer. Thus, polar solvents that solvate the hydroxy group, such as nitrobenzene, nitromethane, acetonitrile, and sulfur dioxide, gave the highest yields of 4-chloro-2-methylphenol. Nonpolar solvents, such as carbon tetrachloride and benzene, which do not solvate the hydroxy group and actually decrease the hydrogen bonding of 2-methylphenol in solution, gave the highest yields of 6-chloro-2-methylphenol. Thus, the ortho/para ratio varied from 0.15 in nitromethane to 1.1 in carbon tetrachloride. The hydrogen bonding of 2-methylphenol in various solvents was observed in the ir.[10] For example, in carbon tetrachloride and benzene, the hydroxy group showed a sharp absorbance at 3618 cm^{-1}, indicating a "free" OH, while a solution of 2-methylphenol in nitromethane and nitrobenzene showed only a broad absorbance at 3545 and 3530 cm^{-1}, respectively, indicating a hydrogen-bonded OH. Similar observations concerning the absorption frequencies of phenols have been previously reported.[11] In regard to solvent effects, a recent article has shown a correlation between the log ortho/para ratio and the dielectric constant for the media in the chlorine chlorination of anisole.[12]

Thus, from the above discussion on hydrogen bonding, it would seem unlikely that ethanol would be a unique solvent to prepare 2-chlorophenol from the *tert*-butyl hypochlorite chlorination of phenol if the reaction is ionic. This explanation was indeed verified by our experimental observations.

Based on previous work with solvents, we decided to investigate the chlorination of phenol with chlorine and *tert*-butyl hypochlorite in carbon tetrachloride to determine what effect temperature and concentration had on the product distribution. These results are listed in Table I.

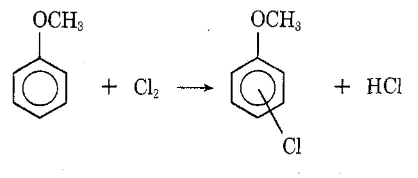
Complete analyses of all reaction products are listed in the Experimental Section. In regard to Table I, it is necessary to list both the maximum yield of 2-chlorophenol and the ortho/para ratio. The maximum yield of 2-chlorophenol is determined from the reaction profile and usually occurs very close to the disappearance of phenol when there are also dichlorophenols formed. It is not possible to determine the maximum yield of 2-chlorophenol from the ortho/para ratio alone. For example, an ortho/para ratio of 2.5 might be expected to yield 72% 2-chlorophenol but actually yields 68.0% owing to unreacted phenol and dichlorophenol present in the product. Chlorination to the extinction of phenol is important from a preparative point of view, since phenol and 2-chlorophenol have very similar boiling points, 182 and 175°, respectively, and form an azeotrope.[13]

The results in Table I show that for the chlorine chlorination of phenol, as the concentration of phenol decreases from a neat to a 5% solution in carbon tetrachloride, the ortho/para ratio increases from 0.65 to 2.5, and the maximum yield of 2-chlorophenol increases from 29 to 68.0%. As the temperature is increased from 18 to 78°, the ortho/para ratio increases from 1.3 to 1.6 and the maximum yield of 2-chlorophenol increases from 52.8 to 57.7%. Similar temperature effects were observed by Campbell and Shields[10] in all the solvent systems they studied. *tert*-Butyl hypochlorite chlorinations of phenol in carbon tetrachloride follow the same pattern. At 78°, a decrease in concentration from 33 to 10% increases the ortho/para ratio from 1.0 to 1.3 and increases the maximum yield of 2-chlorophenol from 47.5 to 53.3%. An increase in temperature from 15 to 78° increases the ortho/para ratio from 0.92 to 1.3 and the maximum yield of 2-chlorophenol from 45.8 to 53.3%. Thus, for the maximum yield of 2-chlorophenol from the chlorination of phenol with either chlorine or *tert*-butyl hypochlorite in carbon tetrachloride, high temperatures and low concentrations should be used.

The above results are consistent with the change in the ortho/para ratio being due primarily to the hydrogen bonding in phenolic solutions, since dilute solutions and high-temperature chlorinations of phenols in nonpolar solvents should shift the equilibrium from a hydrogen-bonded to a nonhydrogen-bonded species. The shift in equilibrium to nonhydrogen-bonded phenols would yield more 2-chlorophenols, since the ortho position would be more available for attack. Evidence for the above explanation can be found in the infrared spectra of phenol in carbon tetrachloride and also in the comparison of the chlorine chlorination of phenol and anisole in carbon tetrachloride.

The infrared spectrum of neat phenol in the hydroxyl stretching frequency region shows only a very broad absorbance at 3350 cm^{-1} which is characteristic of intermolecular hydrogen bonding.[11] When phenol is diluted with carbon tetrachloride to 25, 10, 5, and 1% solutions, there is an increasing appearance with dilution of a sharp absorbance characteristic of a "free" OH at 3615 cm^{-1}. In fact, there is a linear relationship between the ortho/para ratios determined from the chlorine chlorination of phenol in carbon tetrachloride and the amount of "free" or nonhydrogen-bonded phenol as determined from the infrared spectrum. This correlation is shown in Figure 1 and further supports our conclusion that the ortho/para ratio is primarily a function of the amount of hydrogen bonding of phenol in carbon tetrachloride.

Further evidence that the results shown in Table I are due to hydrogen bonding of the phenol can be observed from the chlorination of an aromatic compound, such as anisole, that is of the same reactivity as phenol, but is not capable of strong hydrogen bonding.



Results from the chlorination of anisole with chlorine with and without carbon tetrachloride as a solvent are listed in Table II. The conversions to monochloroanisoles were kept at less than 25% so that accurate para/ortho ratios could be determined. The low conversions are necessary since some of the 4-chloroanisole formed reacts further with chlorine to form 1,3,4,5,6-pentachloro-4-methoxycyclohexene.[14]

The increase in the para/ortho ratio from 4.7 to 6.0 when anisole is chlorinated neat and in a 10% carbon tetrachloride solution, respectively, is minimal when compared to the ortho/para ratio increase from 0.65 to 1.3 when phenol is chlorinated neat and in a 10% carbon tetrachloride solution, respectively. The chlorination of a 10% solution of anisole in refluxing carbon tetrachloride was attempted, but was found to be a very slow reaction, presumably owing to the low solubility of chlorine in carbon tetrachloride at 80°. The above observations further varify that the variation of the ortho/para ratio with concentration and temperature when phenols are chlorinated in nonpolar solvents is primarily due to the phenolic intermolecular hydrogen bonding, since the product distribution varies only slightly when anisole is chlorinated (Table II) but changes dramatically when phenol is chlorinated (Table I). Explanation of the changes in the isomer distribution as seen in Table I based on solvation of the chlorinating agent as noted in the chlorination of alkylbenzenes[15] cannot be operative, since it is known that chlorine does not form a complex with carbon tetrachloride.[16] However, minor changes in the product distribution could also be due to solvation of the active chlorinating species (*e.g.*, R^{-}–Cl^{+}) or solvation of the transition state.

Table II
Chlorine Chlorination of Anisole

Solvent	Concn, wt %	Temp, °C	4-Chloroanisole, %	2-Chloroanisole, %	Para/ortho
None	Neat	25	18.4	3.9	4.7
None	Neat	85	17.2	3.5	4.9
CCl_4	10	25	19.1	3.2	6.0

Based on the previous results that carbon tetrachloride was one of the best solvents for preparing 2-chlorophenols and that high temperatures and low concentrations were also necessary, a series of comparative chlorinations of 10% phenolic solutions in refluxing carbon tetrachloride were run using chlorine and *tert*-butyl hypochlorite. In Table III are listed the results of chlorinating phenol, 2-methylphenol, and 2-chlorophenol.

Table III
Chlorination with Chlorine and *tert*-Butyl Hypochlorite of a 10% Phenolic Solution in Refluxing Carbon Tetrachloride

Reactant	Product	Max yield,[a] wt %	Ortho/para	Max yield,[b] wt %	Ortho/para
Phenol	2-Chlorophenol	57.7	1.6	53.3	1.3
2-Methylphenol	6-Chloro-2-methylphenol	68.3	2.7	62.3	1.9
2-Chlorophenol	2,6-Dichlorophenol	69.0	2.7	63.7	2.2

[a] Yield with chlorine. [b] Yield with *tert*-butyl hypochlorite.

These data clearly show that *tert*-butyl hypochlorite is not a selective ortho-chlorinating reagent for phenols. In fact, chlorine gives higher yields of the ortho chloro isomer in all three examples. It can also be concluded from these results that the ortho selectivity of these reactions is not due to the chlorinating reagent but rather due primarily to the solvent effect previously discussed.

In retrospect, with the knowledge of concentration and temperature dependencies of this reaction, the results of others on the chlorination of phenols with chlorine and *tert*-butyl hypochlorite can be explained. Harvey and Norman[7] obtained an ortho/para ratio of 2.8 when chlorinating a 5.3% phenol solution in carbon tetrachloride with chlorine. Zee[9] obtained an ortho/para ratio of 1.3 when a 23% solution of phenol in carbon tetrachloride was chlorinated with chlorine and an ortho/para ratio of 2.2 with a 7.4% solution. Both chlorinations were run at 20°. Harvey and Norman[7] obtained an ortho/para ratio of 1.0 when 13% solution of phenol in carbon tetrachloride was chlorinated with *tert*-butyl hypochlorite. While there are slight discrepancies, all these results are reasonably consistent with the data in this paper.

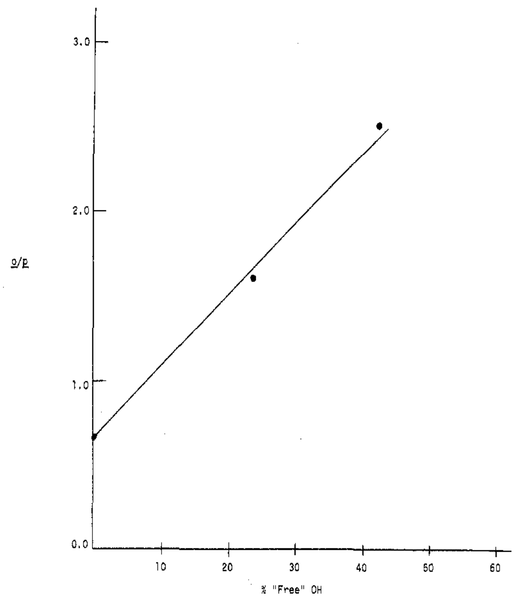


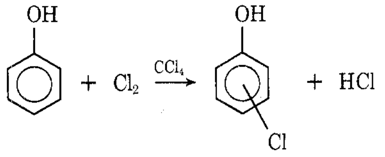
Figure 1. Correlation of ortho/para ratio in the chlorine chlorination of phenol in CCl_4 with the amount of "free" OH.

When Campbell and Shields[10] chlorinated a 25% solution of 2-methylphenol in carbon tetrachloride at 50° with chlorine, they obtained a 47.8% yield of 6-chloro-2-methylphenol and an ortho/para ratio of 1.1, again consistent with our results. No evidence could be obtained for the product distribution described by Ginsburg[4] for the chlorination of 2-methylphenol with *tert*-butyl hypochlorite, *i.e.*, 38% 2-methylphenol, 31% 6-chloro-2-methylphenol, and 18% 4,6-dichloro-2-methylphenol. Our results show a smooth chlorination curve for this reaction, producing 62.3% 6-chloro-2-methylphenol with 1.6% unreacted 2-methylphenol and 3.1% 4,6-dichloro-2-methylphenol. From a preparative point of view, it is necessary to chlorinate to the disappearance of 2-methylphenol since it has a very similar boiling point to that of 6-chloro-2-methylphenol, 191 and 190°, respectively.

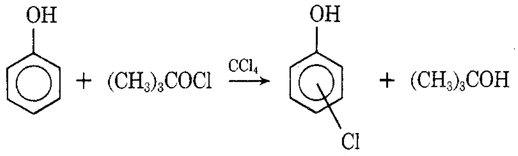
The work of Ginsburg[4] on the chlorination of a 21% solution of 2-chlorophenol in carbon tetrachloride with *tert*-butyl hypochlorite at 25° to reflux giving a 73% yield of 2,6-dichlorophenol also could not be reproduced. Duplication of Ginsburg's procedure resulted in only 51.9% 2,6-dichlorophenol and a 2,6/2,4 ratio of 1.3. One possible explanation for this discrepancy could be the similar boiling points of 2,6-dichlorophenol, 220°, and 2,4-dichlorophenol, 215°, since the mixture was purified by distillation. The dilute chlorine chlorination of 2-chlorophenol in carbon tetrachloride has recently been described in a Russian patent.[17] The patent claims the chlorination of a 7.7% solution of 2-chlorophenol in refluxing carbon tetrachloride to give product that analyzed to be 82.5% 2,6-dichlorophenol with a 2,6/2,4 ratio of 4.8. The 2,6-dichlorophenol produced could then be purified by extraction[17] or crystallization.[18] Other methods of preparing 2,6-dichlorophenol are known.[19]

The fact that different maximum yields of 2-chlorophenols and ortho/para ratios are obtained from the chlorination of the various phenols with chlorine and *tert*-butyl hypochlorite under exactly the same conditions, as shown in Table III, indicates that the two reactions differ to some extent. Recently the chlorination of toluene and *m*-xylene in nitromethane with chlorine and *tert*-butyl hypochlorite has been suggested not to involve the same chlorinating agent, and a direct reaction between the hypohalite and the aromatic was suggested, as evidenced by differences in the product distribution and the rates of reaction.[20]

Inspection of the reaction of phenol with chlorine and *tert*-butyl hypochlorite in carbon tetrachloride shows that, although the reactions can be run under identical conditions such as concentration and temperature, they are still different, since different by-products are produced.



(1)



(2)

Reaction 1 liberates hydrogen chlorine while reaction 2 liberates *tert*-butyl alcohol. The ortho/para ratio remains constant during chlorination (eq 1), implying that the hydrogen chloride has no effect on the product distribution. It is well known from the work of Campbell and Shields[10] that alcohols as solvents increase the yield of para products when compared to carbon tetrachloride. Therefore, it is possible that the *tert*-butyl alcohol that is liberated in reaction 2 is solvating with the phenol and thus decreasing the ortho/para ratio compared to reaction 1. The proposal was tested and confirmed by the simultaneous addition of 1 equiv of *tert*-butyl alcohol/equiv of chlorine in reaction 1. The results are shown in Table IV.

Table IV
Chlorination of 10% Solution of Phenol in Refluxing CCl_4

Chlorinating agent	Additive	Max yield, wt % 2-chlorophenol	Ortho/para
Cl_2		57.7	1.6
$(CH_3)_3COCl$		53.3	1.3
Cl_2	*a*	53.5	1.3

[a] 1 equiv of $(CH_3)_3COH$/1 equiv of Cl_2.

It is doubtful that chlorine would react with the *tert*-butyl alcohol to form *tert*-butyl hypochlorite under these reaction conditions,[5,21] and therefore the results from Table IV clearly show that the differences in the maximum yield of 2-chloro isomer and the ortho/para ratio for the chlorination of phenol, 2-methylphenol, and 2-chlorophenol with chlorine and *tert*-butyl hypochlorite, as shown in Table III, are due to the *tert*-butyl alcohol liberated during the reaction of the phenols with *tert*-butyl hypochlorite.

The similar product distribution shown in Table IV suggests that *tert*-butyl hypochlorite and chlorine react with phenol *via* a common reagent, *i.e.*, chlorine, by an electrophilic aromatic substitution reaction. This is consistant with the known fact that *tert*-butyl hypochlorite reacts under acidic conditions, such as with hydrogen chloride, to form *tert*-butyl alcohol and chlorine.[21]

$$(CH_3)_3COCl + HCl \longrightarrow (CH_3)_3COH + Cl_2$$

Previously, Harvey and Norman[7] had proposed that phenol was acidic enough to cause the above reaction to take place. Our results are consistent with the above.

The fact that the product distribution of the above-described reactions of phenol in carbon tetrachloride with chlorine and *tert*-butyl hypochlorite were unaffected by oxygen, light (200-W Hanovia lamp, mercury arc), and free-radical initiators such as dibenzoyl peroxide further suggests that the reactions described in this paper are ionic and not free radical.

From the data presented in this paper, it can be concluded that *tert*-butyl hypochlorite is not a selective ortho-chlorinating reagent for phenols in either ethanol or carbon tetrachloride. It is also shown that solvents can be used to change the isomer distribution from predominantly 4-chlorophenols to 2-chlorophenols. From a preparative point of view, it appears that dilute chlorine chlorination of phenols in refluxing carbon tetrachloride affords the highest yields of 2-chloro isomer.

Experimental Section

Phenol, 2-methylphenol, and 2-chlorophenol were distilled to ensure high purity (99.8%) and to azeotropically remove water. Absolute ethanol was distilled from magnesium[22] and then from calcium hydride to ensure dryness. Carbon tetrachloride was distilled in glass reagent. Chlorine (99.5%) was obtained from Matheson Corp.

The chlorinations with both chlorine and *tert*-butyl hypochlorite were run using a similar procedure. The phenol and solvent were mixed and the solution was purged with dry nitrogen both before and during the chlorinations. When *tert*-butyl hypochlorite was the chlorinating agent, the lights were turned off to prevent photolytic decomposition.[23] The chlorinating agent was added over a 1–2.5-hr period. During the reaction, small aliquots were withdrawn and after the solvent was removed the chlorophenols were analyzed by vpc. A column 10 ft × 0.125 in. packed with 20% Carbowax 20M terminated with terephthalic acid on 60/80 mesh Chromosorb W (AW-DMCS) and operated at 210° and a helium flow rate of 62 ml/min was used for analyses. In the case of chlorophenols, the elution order is 2-chlorophenol, phenol, 2,6-dichlorophenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol, and 4-chlorophenol. In the case of chloro-2-methylphenols, the elution order is 6-chloro-2-methylphenol, 2-methylphenol, 4,6-dichloro-2-methylphenol, and 4-chloro-2-methylphenol. Anisole chlorination products were analyzed on a 15 ft × 0.125 in. column packed with 10% UCW-98 on 80/100m Gas-Chrom Q operated at 110° isothermally until the 2-chloroanisole eluted and then the temperature was programmed at 10°/min to a final temperature of 175°. The helium flow rate was 25 ml/min. The elution order is anisole, 4-chloroanisole, 2-chloroanisole, 2,6-dichloroanisole, 2,4-dichloroanisole, and 2,4,6-trichloroanisole. Appropriate standards were prepared to convert the analysis to weight per cent. Various samples of chlorophenols prepared with chlorine and *tert*-butyl hypochlorite were examined by mass spectrum, nmr, and ir. Only the listed aromatic products were observed. Analysis by gc using the UCW-98 column described above showed less than 0.5% 3-chlorophenol, which was the lower limit of detectability. Note that all results given in the Experimental Section and throughout this paper are in weight per cent. Details of the procedure and analysis for each experiment are given below.

Preparation of *tert*-Butyl Hypochlorite. *tert*-Butyl hypochlorite was prepared by the method of Mintz and Walling.[23] The *tert*-butyl hypochlorite was used on the day of preparation.

Chlorination of Phenol in Ethanol with *tert*-Butyl Hypochlorite. Phenol (9.41 g, 0.100 mol) was dissolved in ethanol (84.7 g), and *tert*-butyl hypochlorite (10.86 g, 0.100 mol) was added slowly over 1 hr while the temperature was maintained at 15 ± 2°. The product analyzed in weight per cent to be phenol, 1.9; 2-chlorophenol, 30.3; 4-chlorophenol, 65.3; 2,6-dichlorophenol, 0.2; and 2,4-dichlorophenol, 2.3. Another equivalent of *tert*-butyl hypochlorite (10.86 g, 100 mol) was added in 1 hr at 15 ± 2° and the product was analyzed in weight per cent to be 2-chlorophenol, 0.1; 4-chlorophenol, 0.9; 2,6-dichlorophenol, 8.0; 2,4-dichlorophenol, 86.9; and 2,4,6-trichlorophenol, 4.1.

Phenol (9.41 g, 0.100 mol) was dissolved in ethanol (80.46 g) and water (4.24 g). *tert*-Butyl hypochlorite (10.86 g, 0.100 mol) was added slowly over 1.5 hr at 17 ± 2°. The product analyzed in weight per cent to be phenol, 1.7; 2-chlorophenol, 29.4; 4-chlorophenol, 65.4; 2,6-dichlorophenol, 0.4; and 2,4-dichlorophenol, 3.1.

Chlorination of Phenol in Ethanol with Chlorine. Phenol (9.41 g, 0.100 mol) was dissolved in ethanol (84.7 g). Chlorine was sparged into the refluxing solution (79.5°) at a flow rate of 20 ml/min. After 1.75 hr, the solution analyzed in weight per cent to be phenol, 6.6; 2-chlorophenol, 27.5; 4-chlorophenol, 56.0; 2,6-dichlorophenol, 0.8; 2,4-dichlorophenol, 8.2; and 2,4,6-trichlorophenol, 0.9.

Chlorination of Phenol in Carbon Tetrachloride with Chlorine. Phenol (18.82 g, 0.200 mol) was dissolved in carbon tetrachloride (169.4 g), and chlorine gas was added to the refluxing solution (78°) at a flow rate of 41 ml/min for 1.75 hr. The product analyzed in weight per cent to be phenol, 2.9; 2-chlorophenol, 57.7; 4-chlorophenol, 35.9; 2,6-dichlorophenol, 0.2; and 2,4-dichlorophenol, 3.3.

The above procedure was repeated except that the temperature was 18 ± 2°. The product analyzed in weight per cent to be phenol, 2.0; 2-chlorophenol, 52.8; 4-chlorophenol, 39.7; 2,6-dichlorophenol, 0.4; and 2,4-dichlorophenol, 5.1.

Phenol (9.41 g, 0.100 mol) was dissolved in carbon tetrachloride (169.4 g) and chlorine gas was added to the refluxing solution (78°) at a flow rate of 20 ml/min. After 1.8 hr, the product analyzed in weight per cent to be phenol, 2.3; 2-chlorophenol, 68.0; 4-chlorophenol, 26.7; 2,6-dichlorophenol, 0.2; and 2,4-dichlorophenol, 2.8.

Chlorination of Phenol in Carbon Tetrachloride with *tert*-Butyl Hypochlorite. Phenol (18.82 g, 0.200 mol) was dissolved in carbon tetrachloride (169.4 g) and heated to reflux (78.5°). *tert*-Butyl hypochlorite (21.72 g, 0.200 mol) was added in 2.5 hr. The product analyzed in weight per cent to be phenol, 2.2; 2-chlorophenol, 53.3; 4-chlorophenol, 40.6; 2,6-dichlorophenol, 0.6; and 2,4-dichlorophenol, 3.3.

The above procedure was repeated except that the temperature was 15 ± 2°. The product analyzed in weight per cent to be phenol, 1.3; 2-chlorophenol, 45.8; 4-chlorophenol, 49.5; 2,6-dichlorophenol, 0.5; and 2,4-dichlorophenol, 2.9.

Phenol (9.41 g, 0.100 mol) was dissolved in carbon tetrachloride (18.8 g) and heated to reflux (78.5°). *tert*-Butyl hypochlorite (10.86 g, 0.100 mol) was added in 0.5 hr. The product analyzed in weight per cent to be phenol, 2.0; 2-chlorophenol, 47.5; 4-chlorophenol, 47.5; 2,6-dichlorophenol, 0.5; and 2,4-dichlorophenol, 2.5.

Chlorination of 2-Methylphenol in Carbon Tetrachloride with Chlorine. 2-Methylphenol (21.6 g, 0.200 mol) was dissolved in carbon tetrachloride (194.4 g), and after heating to reflux (78.5°) chlorine gas was sparged in at a flow rate of 41 ml/min. After 2 hr, the sample analyzed in weight per cent to be 2-methylphenol, 2.3; 6-chloro-2-methylphenol, 68.3; 4-chloro-2-methylphenol, 26.7; and 4,6-dichloro-2-methylphenol, 2.7.

Chlorination of 2-Methylphenol in Carbon Tetrachloride with *tert*-Butyl Hypochlorite. 2-Methylphenol (21.6 g, 0.200 mol) was dissolved in carbon tetrachloride (194.4 g) and the solution was heated to reflux (79°). *tert*-Butyl hypochlorite (21.72 g, 0.200 mol) was added over 2.3 hr. The product analyzed in weight per cent to be 2-methylphenol, 1.6; 6-chloro-2-methylphenol, 62.3; 4-chloro-2-methylphenol, 33.0; and 4,6-dichloro-2-methylphenol, 3.1.

Chlorination of 2-Chlorophenol in Carbon Tetrachloride with Chlorine. 2-Chlorophenol (25.72 g, 0.200 mol) was dissolved in carbon tetrachloride (231.4 g) and the solution was heated to reflux (80°). Chlorine gas was sparged in and after 2.0 hr the product analyzed in weight per cent to be 2-chlorophenol, 0.5; 2,6-dichlorophenol, 69.0; 2,4-dichlorophenol, 25.5; and 2,4,6-trichlorophenol, 5.0.

Chlorination of 2-Chlorophenol in Carbon Tetrachloride with *tert*-Butyl Hypochlorite. 2-Chlorophenol (25.72 g, 0.200 mol) was dissolved in carbon tetrachloride (231.4 g) and heated to reflux (80°). *tert*-Butyl hypochlorite (21.72 g, 0.200 mol) was added in 2.3 hr. After a slight induction period, the reaction proceeded rapidly to yield a product that analyzed in weight per cent to be 2-chlorophenol, 4.2; 2,6-dichlorophenol, 63.7; 2,4-dichlorophenol, 28.4; and 2,4,6-trichlorophenol, 3.7.

The procedure described by Ginsburg[4] was repeated. 2-Chlorophenol (25.72 g, 0.200 mol) was dissolved in carbon tetrachloride (60 ml). *tert*-Butyl hypochlorite was added over a 1.5-hr period. An induction period occurred when half of the *tert*-butyl hypochlorite was added. The temperature of the reaction rose from 25° to reflux (80°). After all the *tert*-butyl hypochlorite was added, the solution was refluxed for 2 hr. The product analyzed in weight per cent to be 2-chlorophenol, 3.9; 2,6-dichlorophenol, 51.9; 2,4-dichlorophenol, 39.9; and 2,4,6-trichlorophenol, 4.3.

Chlorination of Anisole with Chlorine. Anisole (21.6 g, 0.200 mol) was maintained at 25° while chlorine was introduced for 1 hr. The product analyzed in weight per cent to be anisole, 76.0; 4-chloroanisole, 18.4; 2-chloroanisole, 3.9; 2,6-dichloroanisole, 0.2; 2,4-dichloroanisole, 0.6; 2,4,6-trichloroanisole, 0.1.

The above procedure was repeated at 85°. The product analyzed in weight per cent to be anisole, 77.3; 4-chloroanisole, 17.2; 2-chloroanisole, 3.5; 2,6-dichloroanisole, 0.3; 2,4-dichloroanisole, 1.5; and 2,4,6-trichloroanisole, 0.1.

Anisole (21.6 g, 0.200 mol) was dissolved in carbon tetrachloride (194.7 g) and chlorine was introduced for 1 hr at 25°. The product analyzed in weight per cent to be anisole, 75.9; 4-chloroanisole, 19.1; 2-chloroanisole, 3.2; 2,6-dichloroanisole, 0.5; 2,4-dichloroanisole, 0.7; and 2,4,6-trichloroanisole, 0.1.

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Registry No.—Phenol, 108-95-2; *tert*-butyl hypochlorite, 507-40-4; chlorine, 7782-50-5; 2-methylphenol, 95-48-7; 2-chlorophenol, 95-57-8; anisole, 100-66-3.

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