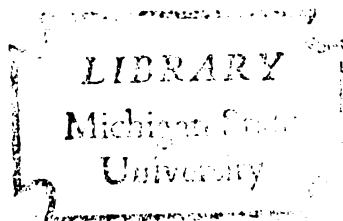REACTION OF ORTHO-
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ALCOHOLS IN THE PRESENCE OF
ANHYDROUS ALUMINUM CHLORIDE

Thesis for the Degree of M. S.
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1944

R.C. Huston

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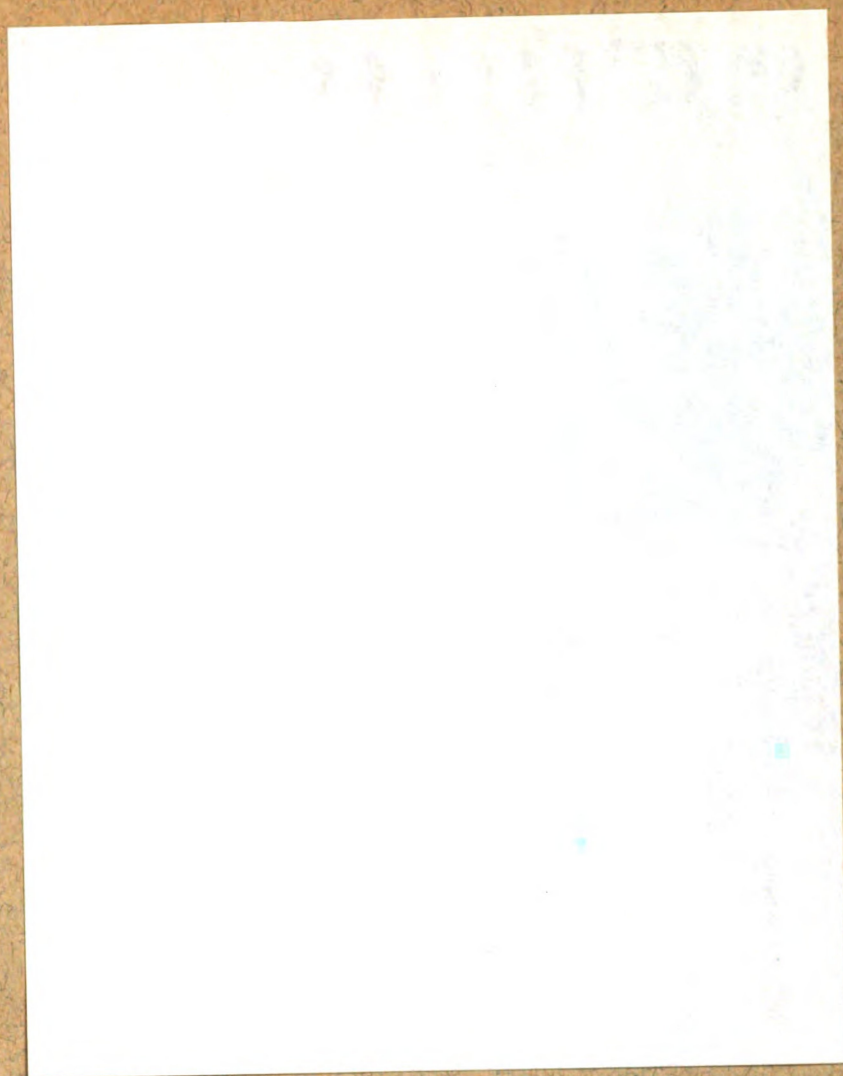
by

AUBREY A. LARSEN

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INTRODUCTION

The condensation of benzene, phenol, and of other aromatic compounds with aliphatic and mixed aliphatic-aromatic alcohols, using anhydrous aluminum chloride as a catalyst, has been the subject of extensive investigations in this laboratory for a number of years.

In 1937, Huston and Coleman (1), investigated the reaction of ortho- and para-chlorophenols with tertiary amyl and butyl alcohols in the presence of aluminum chloride. It was found that both alcohols condensed with o-chlorophenol to yield the p-t-alkyl-o-chlorophenols. These two tertiary alcohols failed to condense with para-chlorophenol under the conditions studied.

It is the purpose of this present investigation to supplement and to extend this work.

The action of anhydrous aluminum chloride and of
other reagents on substituted aromatic compounds, either in,
or not in, the presence of other compounds has been the sub-
ject of investigation since the latter part of the last cen-
tury.

Perrier (2) heated ortho- and para-chlorophenols
with aluminum chloride in dry carbon disulfide and obtained,
upon cooling and filtering, crystalline products which ana-
lyzed as $(C_6H_5OCl)_2Al_2Cl_4$. These compounds had definite
melting points. The original phenols were regenerated by
the action of water.

Dumreicher (3), in 1882, found that $AlCl_3$ reacted
with bromobenzene at elevated temperatures, 130° C., to give
largely unchanged material and some benzene, dibromobenzene,
and HBr. Chlorobenzene was unaffected by $AlCl_3$ under simi-
lar conditions. Iodobenzene gave a reaction similar to that
of bromobenzene, except iodine was recovered instead of HI.

Leroy (4), in 1887, observed that p-dibromobenzene
in the presence of $AlCl_3$ at 100° C., gave tribromobenzene,
monobromobenzene, and meta-dibromobenzene.

Kohn and Fuller (5) debrominated tribromophenol,
with $AlCl_3$ and benzene, at 100° C. Bromobenzene and phenol
were obtained, together with unchanged tribromophenol. Under
similar conditions, trichlorophenol was unaffected.

Kohn and Bum (6) obtained meta-bromotoluene and
phenol from tribromophenol and toluene by the action of

AlCl$_3$ at 100° C. Similarly, p-bromophenol gave meta-bromo-
toluene and phenol.

Kohn (7), in 1931, showed that tribromoresorcinol
was also debrominated by benzene and AlCl$_3$. Aromatic com-
pounds, such as bromochlorobenzene and bromotoluene, also
gave the corresponding debrominated compounds.

Salkind, Stetzaw (8) and Lohfert (9) observed that
when some of the dibromonapthalenes were heated for several
hours in the presence of AlCl$_3$, small amounts of isomeric
dibromonapthalenes, along with the original bromo compounds,
were recovered.

Copisarow (10) observed that when bromobenzene and
AlCl$_3$ were heated on the water bath for eight hours, a mix-
ture of benzene, the three dibromobenzenes, the 1,3,5 tri-
bromobenzene, and some of the 1,2,4 isomer was obtained.
Para-dibromobenzene yielded benzene, bromobenzene, a mixture
of dibromobenzenes, and the 1,2,4- and the 1,3,5-tribromoben-
zenes. Chlorobenzene was not affected by AlCl$_3$. Migration
of the bromine atom was increased by continuous removal of
the benzene formed, and by carrying out the reaction in a
current of HCl or H$_2$.

Berry and Reid (11) alkylated bromobenzene with
ethylene in the presence of AlCl$_3$ and isolated benzene,
ethylbenzene, diethylbenzene, and brominated ethylbenzenes.

Bruce and Todd (12) obtained 1,3-diisopropyl-4-
bromobenzene from the reaction of bromobenzene, isopropyl
chloride, and AlCl$_3$ at 0° C. No debrominated products were

reported.

In most of these instances of bromine migration or removal, the conditions were generally more severe in time, temperature, and in the amount of $AlCl_3$ than usually followed in this laboratory. However, even under these severe conditions, the chloro isologues of these bromo compounds were not dehalogenated.

Suter (13) found that when p-fluorophenetole was refluxed with benzene and $AlCl_3$, the expected p-fluorophenol was obtained, plus some other phenolic product. Weston and Suter (14) later showed that this phenolic product was para-hydroxybiphenyl. Para-hydroxybiphenyl was then obtained directly by the reaction of benzene and $AlCl_3$ with p-fluorophenol. Para-chlorophenol did not show a similar reaction with benzene and $AlCl_3$.

Henne (15) states that $AlCl_3$ replaces fluorine readily in aliphatic or aromatic compounds.

In 1939, Norris and Turner (16), investigated the reaction of the three isomeric chlorotoluenes with $AlCl_3$ and HCl, under mild conditions. They observed both disproportionation and rearrangement as a result of migration by the methyl group.

There is considerable reference in the literature to the dealkylation of alkylaromatics by $AlCl_3$ and other acid catalysts. It has been shown, however, that $AlCl_3$ will remove all types of alkyl groups from an aromatic nucleus. On the other hand, Ipatieff and Corson (17) found that

ferric chloride, sulfuric acid, and phosphoric acid remove only tertiary alkyl groups readily from an aromatic nucleus.

Crlov and Vaisfeld (18) studied the dealkylation of xylenes and found that moist $AlCl_3$ was very effective for dealkylation, $AlCl_3 \cdot 6H_2O$ being the most effective.

Nightingale (19) gives an extensive review of both alkylation and dealkylation of benzene in the presence of $AlCl_3$.

Nitration is, in many respects, analogous to alkylation. There are innumerable references in the literature where debromination was observed when bromoaromatics were nitrated.

In 1896, Jackson and Dunlap (20) obtained unidentified debrominated products from 2,4,6-tribromoresorcinol by the action of boiling water.

Baichikov and Zadbrodkin (21) obtained picric acid and bromine by the action of a nitric-sulfuric acid mixture on symmetrical tribromophenol. Without the sulfuric acid, the amount of debromination was small.

Raiford and Heyl (22, 23) found that both tribromo and triiodophenol had either an ortho or a para halogen replaced by a nitro group when these phenols were treated with sodium nitrite and acetic acid. Trichlorophenol was unaffected under the same conditions.

Raiford and LeRosen (24) nitrated brominated fluorophenols by acetic acid and sodium nitrite. When 2,4,6-tribromo-3-fluorophenol was nitrated, a bromine atom was

replaced by a nitro group in either the "2" or the "4" position. When 2-fluoro-4,6-dibromophenol was nitrated, the products were 2-fluoro-4-bromo-6-nitrophenol and 2-fluoro-4-nitro-6-bromophenol. The product from 2,6-dibromo-4-fluorophenol was 2-bromo-4-fluoro-6-nitrophenol.

Similarly, Raiford and Miller (25) studied chlorobromophenols under like conditions and in all cases, it was the bromine that was replaced by the nitro group.

Emerson, Dorf, and Deutschmann (26) observed a debromination of tribromoaniline when refluxed with zinc, HCl, acetic acid, and formaldehyde. The resultant product was dimethyl-p-bromophenylamine.

Hodgson and Nixon (27) subjected 4-chloro-3-nitroaniline to diazotization with $NaNO_2$ and either HCl or H_2SO_4. Depending upon the acidity of the solution, the product was a 4-chloro-2-nitrobenzenediazonium salt or 2-nitrobenzene-4-diazo oxide-1. In the case of 4-fluoro-3-nitroaniline, the product was exclusively 2-nitrobenzene-4-diazo oxide-1.

In this laboratory, bromo and chloro compounds have been reacted in the presence of minimum amounts of $AlCl_3$ at room temperature without any observed dehalogenation.

Huston and Warren (28) benzylated o-chlorophenol in the presence of $AlCl_3$ to obtain both 4-benzyl-2-chlorophenol and 6-benzyl-2-chlorophenol.

Huston and Guile (29) reacted meta-chlorobenzylchloride and 2,6-dichlorophenol in the presence of $AlCl_3$ to

obtain 4-hydroxy-3-5-3'-trichlorodiphenylmethane.

Para-bromobenzylchloride was reacted with both phenol and 2,6-dibromophenol by Huston and D'Arcy (30) to give 4-hydroxy-4'-bromodiphenylmethane and 4-hydroxy-3,5,4'-tribromodiphenylmethane.

Huston and Fayerweather (31) successfully obtained 4-hydroxy-2'-bromodiphenylmethane and 2-hydroxy-2'-bromodiphenylmethane from ortho-bromobenzylchloride and phenol in the presence of $AlCl_3$.

Huston and Neely (32) benzylated 2,6-dibromophenol with meta-bromobenzylchloride to yield 4-hydroxy-3,5,3'-tribromophenylmethane.

Huston and Strickler (33) reported the condensation of n-propylphenylcarbinol and 2,6-dibromophenol with $AlCl_3$ to give 4(alpha-phenylbutyl)-2,6-dibromophenol.

2,6-dichlorophenol was condensed with benzyl alcohol and $AlCl_3$ by Huston and Eldridge (34) to give 4-hydroxy-3,5-dichlorodiphenylmethane and the corresponding ether.

In 1937, Huston and Coleman (1), investigated the reaction of ortho- and para-chlorophenols with tertiary amyl and tertiary butyl alcohols in the presence of $AlCl_3$ at room temperature.

Tertiary butyl and tertiary amyl alcohols both condensed with o-chlorophenol to give the para-t-alkyl ortho-chlorophenols. Both of the alcohols failed to condense with para-chlorophenol under the conditions studied.

Klarmann, Shternov, and Gates (35), in 1933,

prepared para-t-amyl-ortho-chlorophenol without reporting the method of preparation.

Para-t-butyl-o-chlorophenol was prepared by Mills (36) by the chlorination of p-t-butyl-phenol.

Similarly, Klarmann, Gates, Shternov, and Cox (37) brominated p-t-amyl phenol to give p-t-amyl-o-bromophenol. Mills (36), by the same procedure, obtained a similar product.

In 1895, Dains and Rothrock (38), prepared p-t-butyl-o-bromophenol by brominating, in carbon disulfide, the sodium salt of p-t-butylphenol. After distillation, a dark oil was left which was best purified by steam distillation. The oil then solidified and was identified as p-t-butyl-o-bromophenol.

Huston and Agett (43) brominated p-t-butylphenol and obtained p-t-butyl-o-bromophenol. The reaction of para-bromophenol with tertiary butyl alcohol in the presence of $AlCl_3$ was also investigated. No alkylated product was obtained, 73% of the original phenol being recovered. In the reaction of the tertiary butyl alcohol with p-bromophenol in the presence of phosphoric acid, 95% of the original phenol was recovered.

A. Materials

1. Ortho-bromophenol

The method of Huston and Neeley (39) was used to prepare o-bromophenol.

Three moles (282 grams) of U.S.P. phenol and eight moles (820 grams) of concentrated sulfuric acid (density, 1.84) were placed in a five liter, three neck flask, and were heated at 100-110° C., with stirring, for two to three hours. After the solution had cooled, 700 grams of freshly distilled nitrobenzene were added. The solution was cooled with an ice and salt bath, and 150 grams of melted, fuming sulfuric acid (40%) were added, with stirring, and at such a rate that the temperature of the solution did not exceed 10° C. After bringing the solution to room temperature, 300 grams (3.8 moles), of bromine in 500 grams of freshly distilled nitrobenzene were added, with stirring, over the course of three to four hours. Stirring was continued for three to six hours after all the bromine had been added. Then, sufficient $NaHSO_3$ was added to reduce the excess bromine. Enough water was added to fill the flask and the two layer system was stirred for a short time to extract the sulfonated phenols.

The water layer was then separated from the nitrobenzene layer. The water layer was then subjected to distillation. When the temperature of the water solution reached 115-125° C., the characteristic odor of o-bromophenol was

noticeable in the distillate. At this point, the oil bath temperature was raised to 200° C., and superheated steam $(200^o$ C.), was passed into the flask. The o-bromophenol steam distilled rapidly as the superheated steam hydrolyzed the sulfonic acid groups.

The two layer distillate was extracted with ethyl ether and the resulting ether layer dried over anhydrous Na_2SO_4, in the cold.

The ether was boiled off and the phenol residue was subjected to vacuum distillation. The o-bromophenol was distilled twice at reduced pressure through a 60 cm. glass-packed, heated column. The resulting o-bromophenol boiled at $76-77^o$ C., at 11 mm., and yields of $30-35\%$ were consistently obtained. Analysis: Calculated for C_6H_5OBr. Br, 46.2. Found: Br, 45.9 - 46.4. Refractive index, N_D^{20} = 1.5747.

2. Ortho-chlorophenol

Eastman's white label o-chlorophenol was used. As with o-bromophenol, the material became colored upon standing if it was not pure. The o-chlorophenol was distilled at least twice before using, through a 45 cm. modified Claisen flask, and has a boiling point of $66-67^o$ C. at 13 mm.

3. Para-chlorophenol

The p-chlorophenol obtained, an oily solid, was best purified by distillation. The purified phenol boiled at $88-89^o$ C. at 3 mm. through a 45 cm. modified Claisen flask.

4. Tertiary Butyl and Tertiary Amyl Alcohols

Both of these alcohols form constant boiling mixtures with water. Young and Fortey (40) found that tertiary butyl alcohol forms a mixture which boils at 79.9° C. at 760 mm. and contains 21.7% water. Similarly, Ayres (41) showed that tertiary amyl alcohol forms a mixture which boils at 87.2° C. and contains 22% water.

Both alcohols were distilled several times, the foreruns being discarded. To insure complete removal of all water, the twice distilled alcohols were again distilled over sodium, the amount of sodium being 1/50 of the weight of the alcohol being distilled. In this manner, t-butyl alcohol, boiling at 80-81° C. at 744 mm., and t-amyl alcohol, boiling at 99-100.5° C. at 737 mm., were obtained.

5. Petroleum Ether

The petroleum ether was tested for unsaturated compounds before use and was then dried over sodium.

6. Aluminum Chloride

Baker's analyzed, anhydrous, sublimed $AlCl_3$ was used. No difference was observed in the over-all catalytic action between the granular and the pea size $AlCl_3$.

7. Acetic Anhydride

Eastman's yellow label (practical) acetic anhydride was distilled and the fraction boiling from 135-137° C. at 743 mm. was used.

A 500 ml. three neck flask was fitted with a mer-
cury seal stirrer, a condenser, and a thermometer. To the
flask was added ¼ mole (32 grams) of o-chlorophenol, ¼ mole
(18.5 grams) of t-butyl alcohol, and 150 ml. of anhydrous
petroleum ether. The flask and contents were cooled to 0-10°
C., the cooling was then removed, and the anhydrous $AlCl_3$
was added. In most cases the temperature was not allowed to
go above 30 ° C. The rate of addition of the $AlCl_3$ was used
as much as possible to keep below the desired temperature.

As the $AlCl_3$ was added, the reaction mixture went
through a series of color changes, usually ending up with an
orange-red color. Ten to fifteen minutes after the first
$AlCl_3$ had been added, a precipitate other than undissolved
$AlCl_3$ formed or settled out in the reaction mixture. The
stirring was continued for five to eight hours after all of
the $AlCl_3$ had been added, and the reaction mixture was then
left to stand overnight.

Ice, water, and concentrated HCl were added to the
reaction mixture. The upper petroleum ether layer, violet
in color, was separated from the water layer. The water lay-
er was washed three times with ethyl ether and then the
ether washings were added to the original petroleum ether
layer. The combined ether layers were washed three times
with water, as o-halophenols cannot be washed with Na_2CO_3,
Wohlleben (42), and the color of the ether layer changed
from violet to brown. Then the ether layer was placed over

anhydrous Na_2SO_4 in the cold to dry.

After drying, the ether solution was subjected to fractional distillation.

The following is a representative fractionation of the ether solution from the reaction. A 60 cm. glass-packed, heated column was used.

1. up to 40° C. at 738 mm.   Did not decolorize Br_2.
   Gave a positive Beilstein test.

2. 40 to 50° C. at 738 mm.   Did not decolorize Br_2.
   Gave a positive Beilstein test.

3. 50 to 55° C. at 738 mm.   Decolorized Br_2.
   Discharged color of neutral $KMnO_4$.
   Gave a positive Beilstein test.
   Positive test with alcoholic $AgNO_3$.

4. 55 to 60° C. at 738 mm.   Same as #3.

As the oil bath temperature was raised to 180° C., there was little or no further distillate until the pressure was reduced.

5. up to 100° C. at 7 mm.   Very little distillate was obtained above 60-61° C., the boiling point of o-chlorophenol at this pressure.

6. 100 to 110° C. at 7 mm.   Bulk of the material was p-t-butyl-o-chlorophenol which boiled at 105-108° C.

7. On occasions, a small amount of liquid was obtained above the range of fraction six. This amount was never more than 2 or 3 milliliters.

8. Resulting residue was black and viscous and showed no signs of crystallizing after standing for six months.

Above the range of the volatile distillate, there was very

little material other than the unreacted o-chlorophenol and
the alkylated product.

The o-chlorophenol from fraction ,5 became deeply
colored and had to be redistilled several times before it
remained clear.   The alkylated chlorophenol did not become
colored in this manner.

The amount of material boiling from 50-55° C.,
fraction 3, was always very small.   If there were any un-
reacted t-butyl chloride present, it would have been found
in this fraction.   Tertiary butyl chloride gives a positive
test for unsaturation.

No material boiling from 78-83° C., the boiling
range of t-butyl alcohol, was obtained.

On repeated fractionation, p-t-butyl-o-chlorophen-
ol, with a boiling point of 93-94° C. at 3mm., was obtained.

The diphenylurethan derivative, recrystallized
from petroleum ether, had a melting point of 140-141° C.
Coleman (1) reported the melting point of this derivative as
142-143° C.

<div align="center">

Para-t-butyl-o-chlorophenol

$D_4^{20} = 1.0908$

$N_4^{20} = 1.5309$

$B.P._{745} = 238.8-239°$ C.

</div>

Surface Tension: 34.2   dynes/cm. (Drop Weight)
Surface Tension: 35.2   dynes/cm. (Du Nuoy)

Analysis.   Calculated for $C_{10}H_{13}OCl$:   Cl, 19.21

<div align="center">Found: Cl, 19.37</div>

Mills (36) reported the density of p-t-butyl-o-chlorophenol as $D_{25}^{25} = 1.099$.

Eleven condensations, in which the molar quantity of $AlCl_3$ was varied, were run with t-butyl alcohol and o-chlorophenol. The results of these runs are tabulated below.

Run Number	Molar Quantity of $AlCl_3$	Highest Reaction Temperature	Per Cent Yield of P-t-butyl-o-chloro-phenol	Color of Reaction After Addition of all $AlCl_3$	General Remarks
1	1.0	40° C.	34%	light red	
2	1.0	30° C.	52%	orange	
3	1.0	33° C.	54%	orange	
4	1.0	35° C.	48%	orange	
5	0.60		0	violet	$AlCl_3$ was not anhydrous
6	0.60	30° C.	47%	orange	
7	0.40	34° C.	10%	orange	80% recovery o-chlorophenol
8	0.40	31° C.	0	violet	92% recovery o-chlorophenol
9	0.50	30° C.	35%	orange	
10	0.50	27° C.	0	violet	89% recovery o-chlorophenol
11	0.60	31° C.	50%	red orange	

The method of condensing t-amyl alcohol with o-chlorophenol was the same as that used to condense t-butyl alcohol with o-chlorophenol. As in the previous condensations, the distillation yielded sharp fractions which were easily and cleanly separated.

The yield of p-t-amyl-o-chlorophenol varied with the molar quantity of $AlCl_3$. Fifty per cent yields were obtained when more than 0.6 of a molar quantity of $AlCl_3$ was used. Below this amount, the yields dropped off as the amount of $AlCl_3$ was decreased.

Para-t-amyl-o-chlorophenol has a B.P. of 119-121° C. at 8 mm. and 103-104° C. at 1 mm. The diphenylurethan derivative, recrystallized from petroleum ether, had an M.P. of 113.5-115° C. Coleman (1) reported the melting point of this derivative as 116-117° C.

Para-t-amyl-o-chlorophenol

$$D_4^{20} = 1.0305$$

$$N_4^{20} = 1.5313$$

$$B.P._{745} = 257.6-258° C.$$

Surface Tension: 34.7 dynes/cm. (Drop Weight)
Surface Tension: 35.8 dynes/cm. (Du Nuoy)

Analysis. Calculated for $C_{11}H_{15}OCl$: Cl, 17.85

Found: Cl, 17.69

D. Condensation of Tertiary Butyl And Tertiary Amyl Alcohols With Para-chlorophenol

These two alcohols failed to condense with para-chlorophenol in the presence of $AlCl_3$, either at room temperature or at slightly elevated temperatures, 45-60° C.

The general method of carrying out these reactions was the same as that used for o-chlorophenol and t-butyl and t-amyl alcohols. A Skellysolve was used in the place of petroleum ether for the higher temperature runs. The amount of $AlCl_3$ was varied between 0.5 and 1.0 of a molar quantity. Recovery of at least 90% of the original phenol was observed in all cases.

1. Preliminary Investigations

In view of the results obtained from the condensations of o-chlorophenol with t-butyl and t-amyl alcohols, it was decided to carry out this part of the investigation under similar conditions. At the start of this series of condensations,the removal of bromine from aromatic compounds in the presence of $AlCl_3$ was known to the writer, but its significance was not appreciated.

A quarter of a mole of o-bromophenol and one quarter of a mole of the alcohol were added to 150 ml. of anhydrous petroleum ether. The solution was cooled and 0.6 x $\frac{1}{4}$ of a mole of $AlCl_3$ was slowly added, at the same time keeping the temperature of the reaction mixture below 30° C. The resulting mixture was stirred, allowed to stand, and was then worked up in the usual manner. After drying the ether extracts, the ether was removed and the residue was distilled at reduced pressure.

Unreacted o-bromophenol was collected. The vapor temperature rose steadily and then a solid distillate, with both t-butyl and t-amyl alcohols, was obtained. This distillate solidified in the side arm of the modified Claisen flask and in the receiver. Less trouble with solidification was experienced when a water pump was used for obtaining the reduced pressure.

The solid material looked like a definite crystalline substance, together with a smaller amount of an oily

liquid. This mixture melted over a wide temperature range.

Repeated distillation effected little separation of the solid materials. When synthetic mixtures of p-t-alkylphenol and p-t-alkyl-o-bromophenol were distilled, a solid material, similar to that recovered from the $AlCl_3$ condensation, was obtained.

Other physical methods were then tried in order to effect a separation. Among these were steam distillation from an alkaline solution, recrystallization from petroleum ether or from benzene, extraction with NaOH (and subsequent treatment of the alkaline solution with HCl and ether), and extraction with boiling water. In all of these cases, p-t-alkylphenol, in varying degrees of purity, was obtained. In none of these cases,however, was separation selective enough to completely separate the alkylphenol from the other product or products in the solid distillate.

Acetylation of the various phenols that might be in the solid distillate material showed that the acetates could be separated by fractional distillation, and that the original phenol could be readily regenerated from the acetate. Similarly, phenol can be separated from o-bromophenol by this method. With this means of separation, a more thorough investigation of the condensation of o-bromophenol with t-amyl and t-butyl alcohols was undertaken.

2. Condensation of t-Butyl Alcohol With o-Bromophenol

One half a mole (86.6 grams) of o-bromophenol and one half a mole (37 grams) of t-butyl alcohol were dissolved in 200 ml. of anhydrous petroleum ether. The solution was cooled with ice, the cooling was removed, and then 40 grams (0.6 x ½ mole) of $AlCl_3$ were slowly added, with the temperature of the reaction mixture being kept below 30° C. The usual color changes were observed, acid gas was given off, and a solid material settled out of the solution about twenty minutes after the first $AlCl_3$ had been added. The mixture was left to stir, at room temperature, for seven hours. The reaction mixture was worked up in the usual manner and the ether layers were then placed over anhydrous Na_2SO_4 in the cold to dry. After drying, the ether was removed and the residue was separated into three main fractions by distillation at reduced pressure.

Fraction #	I	120° C. at 13 mm., 48.9 grams
Fraction #	II	120 - 124° C. at 13 mm., 50. grams
		Solidified in receiver.
Fraction #	III	107 - 110° C. at 3 mm., 2. grams
Fraction #	IV	Residue.

Fraction #I was redistilled and the resulting liquid, boiling at 80-83° C. at 13 mm., was analyzed for bromine by the Carius method. Found, Bromine, 43.4%. Theory for o-bromophenol, 46.2% bromine. On the basis that o-bromophenol was the only bromo compound present, this distillate was 93.7% o-bromophenol. The other material

present was considered, without further investigation, as phenol, according to Wohlleben (42).

Fraction #II was analyzed for bromine by the Parr Bomb method, and was found to contain 5% bromine. On the basis that the bromo compound present was p-t-butyl-o-bromophenol, the analysis indicated that the solid distillate material contained 14% p-t-butyl-o-bromophenol.

This analysis further showed that the crude yield of the p-t-butylphenol was 52% of theory and the yield of p-t-butyl-o-bromophenol was 6% of the theoretical.

With the results from the bromine analysis, fraction #II was acetylated. The resulting acetylated material was distilled at reduced pressure.

Fraction # I   110-120° C. at $3\frac{1}{2}$ mm., 3.4 grams, $N_D^{20} = 1.5061$

Fraction # II   120-126° C. at $3\frac{1}{2}$ mm.,36.6 grams, $N_D^{20} = 1.5001$

Fraction #III   130-138° C. at $3\frac{1}{2}$ mm., 7.8 grams, $N_D^{20} = 1.5227$

Part of the acetylated material from fraction #II was saponified. The resulting crystals, after recrystallization from petroleum ether, were identified as p-t-butylphenol.

p-t-Butylphenol

M.P. 96-97° C.

Analysis. Calculated for $C_{10}H_{14}O$: C, 79.95; H, 9.39

Found: C, 79.12; H, 8.71

Benzoate derivative. M.P. 80-82° C.

Fraction #III from the acetylation was saponified

and 3.6 grams of material, boiling at 108-110° C. at 3 mm., were recovered.

Upon standing, crystals were obtained from this distillate, which melted from 25-45° C. Recrystallization from petroleum ether did not improve the melting point of this material. The alpha-naphthylurethan derivative of this material was made. M.P. 204-205° C. The analysis for bromine by the Parr Bomb method showed 19.88% bromine. Theory for $C_{21}H_{20}O_2NBr$, 20.07% bromine.

Para-t-butyl-o-bromophenol, made by bromination of p-t-butylphenol, gave an alpha-naphthylurethan which melted at 205-206° C. The mixed melting point of these two urethans was 204-205° C.

3. Condensation of t-Amyl Alcohol With o-Bromophenol

One half a mole (86.6 grams) of o-bromophenol and one half a mole (44 grams) of t-amyl alcohol were added to 200 ml. of anhydrous petroleum ether. The solution was cooled with ice, the cooling was removed, and then 40 grams (o.6 x ¼ mole) of anhydrous $AlCl_3$ were slowly added, with the temperature of the reaction mixture being kept below 30° C. The usual phenomena were observed. The reaction mixture was left to stir for eight hours at room temperature. The reaction mixture was worked up in the usual manner, dried, and the ether was removed.

The residue from the ether distillation was fractionated at reduced pressure.

Fraction # I 73° C. at 9mm.

Fraction # II 72° C. at 9mm. - 110° C. at 2mm., 54.0 grams

Fraction #III 110° C. at 2mm. - 112° C. at 2mm., 40.3 grams
                                      Material solidified in receiver.

Fraction # IV   Residue

Fraction #II was redistilled and 48.7 grams of material were collected at 78-80° C. at 12 mm. This fraction was analyzed for bromine by the Carius method. Found, 42.70% bromine. Theory for o-bromophenol, 46.2% bromine. On the basis that o-bromophenol was the only bromo compound present, this distillate was 92.5% o-bromophenol.

Fraction #III was analyzed for bromine by the Parr Bomb method and showed 7% bromine.

On the basis that only p-t-amylphenol and p-t-amyl-o-bromophenol were present, the analysis that the material was 20% p-t-amyl-o-bromophenol and the yield of this compound was 6.6% of theory. The yield of p-t-amylphenol was 39% of theory.

With the results from the bromine analysis, all of fraction #III was acetylated and the resulting acetate mixture was distilled at reduced pressure.

Fraction #   113° C. at 1 mm.

Fraction # II   113-110° C. at 1 mm., 25.6 grams, $N_D^{20} = 1.5005$

Fraction #III   116-130° C. at 1 mm., 13.0 grams, $N_D^{20} = 1.5070$

A part of fraction #II from the acetylation distillation was saponified. The resulting crystals, after recrystallization, were identified as p-t-amylphenol.

<div align="center">

p-t-Amylphenol
M.P. 92-92.5° C.

</div>

Analysis. Calculated for $C_{11}H_{16}O$: C, 80.44; H, 9.82

    Found: C, 80.27; H, 9.67

   Benzoate derivative. M.P. 58-60° C.

Fraction #III from the acetylation was redistilled and 6.6 grams of material, boiling at 123-124° C. at ½ mm., $N_D^{20} = 1.5211$ were obtained.

This material was saponified with aqueous NaOH and heat. Upon distillation, 4.0 grams of phenolic material, boiling at 116-118° C. at 2 mm., were recovered.

p-t-Amyl-o-bromophenol

$$N_D^{20} = 1.5507$$

$$D_4^{20} = 1.3168$$

Analysis. Calculated for $C_{11}H_{15}OBr$:   Br, 32.87

Found: Br, 33.20

The alpha-naphthylurethan derivative of this material had a melting point of 149-150° C. Analysis for bromine showed 18.81% bromine. Theory for $C_{22}H_{22}O_2NBr$, 19.38% bromine.

Para-t-amyl-o-bromophenol, made by bromination of p-t-amylphenol, gave an alpha-naphthylurethan which melted at 153-154° C. The mixed melting point of these two urethans was 149-150° C.

Physical Constants of the Phenols and Acetates Involved in
The Condensation of Tertiary Amyl and Tertiary Butyl
Alcohols With Ortho-bromophenol

Compound	Boiling Point	N_D^{20}	D_4^{20}
phenylacetate	70 - 72° C. 4 mm.	1.5036	·
o-bromophenylacetate	101 - 102° C. 4 mm.	1.5393	
p-t-butylphenylacetate	121 - 125° C. 3½ mm.	1.4998	1.0188
p-t-amylphenylacetate	121 - 123° C. 3 mm.	1.5000	0.9948
p-t-butyl-o-bromophenylacetate	124 - 126° C. 1½ mm.	1.5295	1.3092
p-t-amyl-o-bromophenylacetate	131 - 133° C. 1 mm.	1.5273	1.2790
p-t-butyl-o-bromophenol	108 - 110° C. 3 mm.	1.5446	1.2713
p-t-amyl-o-bromophenol	116 - 118° C. 2 mm.	1.5507	1.3168
p-t-butylphenol	M.P.96-97° C.		
p-t-amylphenol	M.P. 92° C.		

The method of Chattaway (44) was used for making the acetates of the distillate mixtures.

One tenth of a mole of the phenol was dissolved in an aqueous solution containing six grams (0.15 moles) of NaOH. The NaOH had been dissolved in enough water to barely give a liquid solution of the phenolate. The phenolate solution was cooled, 50 grams of crushed ice were added, followed by the addition of 12.8 grams (0.125 moles) of acetic anhydride. The solution was stirred for a minute or less, ether was added, and the two layers were separated. The aqueous layer was washed several times with ether and the combined ether layers were washed with water. As the acetates are easily saponified by a basic solution, according to Fischer and Grutzner, (45), it is necessary to wash the ether layer as soon as possible to remove any base present. The acetylation mixture should be alkaline after the addition of the acetic anhydride. Sufficient aqueous NaOH was added if the solution was not basic.

Upon distillation, yields of acetates above 75% were obtained.

The original phenol was recovered from the acetate by addition of aqueous NaOH to the acetate and heating on a steam bath until a clear solution resulted. The p-alkyl-phenylacetates were hydrolyzed very easily. The p-alkyl-o-bromophenylacetates needed a stronger basic solution to effect saponification. More than 70% of the acetate is recovered as the corresponding phenol.

1. Diphenylurethans

The method used for preparing these derivatives was exactly the same as given by Shriner and Fuson (46).

2. Benzoates

One gram of the phenol was added to a solution of three milliliters of pyridine and one milliliter of benzoyl chloride. The mixture was heated for three to four minutes and was then added to ten milliliters of H_2O. The water was extracted with ethyl ether. The ether layer was washed with dilute sulfuric acid, 10% sodium carbonate, and then with water. Ethyl alcohol was added to the ether layer and the ester crystallized by evaporation of excess solvent and cooling.

## 3. Alpha-naphthylurethans

One gram of the phenol was added to one milliliter of alpha-naphthylisocyanate containing a few drops of an ether solution of trimethylamine. The flask was stopped with a cork, to which was attached a drying tube. The flask was shaken and was then placed on the steam bath to heat for ten to twenty minutes. Upon cooling, the solid mass which formed was heated with fifty to sixty milliliters of petroleum ether. The insoluble material was filtered off, and the urethan was recovered from the filtrate by evaporation of the excess solvent.

In the cases where bromine is removed or replaced by a cationoid agent, removal seems to be most easily accomplished when the bromine is ortho or para to a strong ortho-para director. Conversely, DeCrauw (47) has reviewed the replacement of bromine by anionoid agents, such as -OH, -OCH$_3$, and -NH$_2$, and observed that halogen removal is easiest when the halogen is meta to a strong ortho-para director, or ortho-para to a meta director. His summary further showed that the halogens are replaced in the following order: F $>$ I $>$ Br $>$ Cl by a group such as -OH or the -OCH$_3$ group.

Though the literature contains very little concerning the action of AlCl$_3$ on fluorine aromatics, it would seem that fluorine, bromine, and iodine, but not chlorine, are removed by the action of AlCl$_3$.

For an interpretation of the removal of bromine and halogen in aromatic compounds, and especially from o-bromophenol, the cationoid theory of substitution, as outlined by Price (48), offers the most logical explanation.

In cationoid substitution, an electron deficient reagent replaces a proton in the benzene nucleus in the following manner:

$$\bigcirc + \left[\ddot{S} \colon \right]^{+} \rightleftharpoons \left[\bigcirc \genfrac{}{}{0pt}{}{H}{H} S \right]^{+} \rightleftharpoons \bigcirc S + H^{+} \quad (I)$$
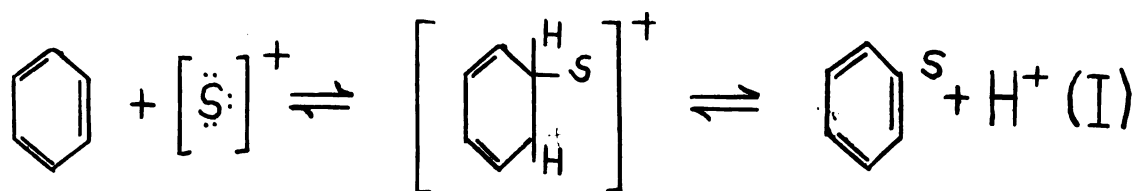
Then the benzene ring undergoing substitution already has an anionoid substituent present, the ease of

substitution is increased, due to the greater availability of electrons within the ring. Under such conditions, two or three cationoid agents may be added to the benzene ring in positions ortho and para to the directing and activating substituent.

The second step of equation #I is not readily reversible when an inert solvent is used and the acidity of the solution is at a minimum. When benzene is brominated in an inert solvent, the HBr liberated is not acid enough to reverse the process causing debromination. When, however, a strong acid such as $AlCl_3$ or H_2SO_4 is present, the second step is reversible and debromination can occur.

In a similar manner, di- and trialkylaromatics can be dealkylated in the presence of a strong acid. $AlCl_3$ has been found to be the most effective for dealkylation (17).

In addition to the presence of both $AlCl_3$ and protons in the reaction mixture, the particular structure of o-bromophenol may lend itself to debromination.

In o-bromophenol, an electron tension may arise between the two substituted carbon atoms. Both hydroxyl and bromine are ring activators, bromine much less so than hydroxyl, and each increases the electron density in the ortho and para positions in relation to its own position. As a result, a high electron density would arise between the two substituted carbon atoms. Under these conditions, a strong acid such as $AlCl_3$ could attach itself to one of the electron pairs between these two carbon atoms, forming a dative

bond.   The loss of the Br^+ would then restore the aromatic ring character.   A proton could then replace the $AlCl_3$, either during the reaction,   or upon hydrolysis   with water and acid, with the formation of the debrominated product.
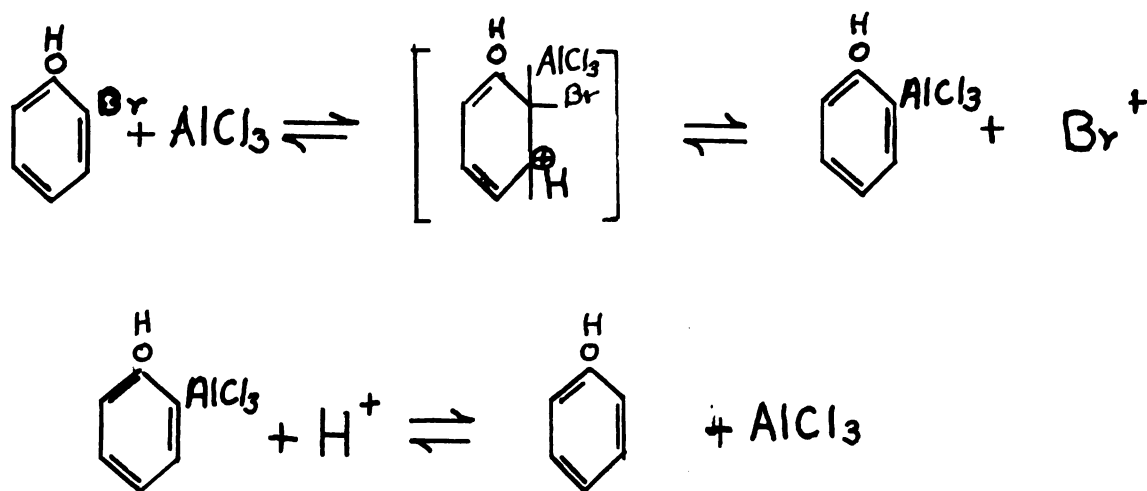
When debromination occurs in the presence of H_2SO_4, the proton adds directly to the aromatic ring. The net result,   with either $AlCl_3$ or H^+, is the reverse of cationoid substitution.

With bromobenzene and $AlCl_3$ at 100° C., it seems necessary to assume that it is the $AlCl_3$ which adds to the ring, for under these conditions, there would be little likelihood that a sufficient concentration of protons would be present to effect debromination.

Copisarow (10) showed that the passage, at a slow rate, of HCl or H_2 through a reaction mixture containing

one mole of bromobenzene and amounts of $AlCl_3$ up to six-tenths of a mole of $AlCl_3$, increased the extent of bromine removal and migration. When phenol was added to the reaction mixture to fix the bromine, the removal of bromine from bromobenzene was not improved, due to the reaction of the $AlCl_3$ with the hydroxyl group. The writer found, however, that both of the o-halophenols, in the presence of $AlCl_3$ and a tertiary alcohol, at room temperature or below, did not evolve a significant quantity of HCl until fifty to sixty minutes after the addition of the first $AlCl_3$. The presence of a hydroxyl group need not necessarily hinder the removal of bromine by $AlCl_3$ from an aromatic nucleus, if the reaction is carried out at a temperature low enough so that the evolved HCl is not removed as soon as it is formed.

Whether it is $AlCl_3$ itself, or protons, or a combination of both of these, which is the active agent in effecting debromination, cannot be determined with the present information.

It suffices to say, at this time, that the debromination of o-bromophenol is probably the result of two factors: (1) The labile character of the bromine in o-bromophenol, and (2) The continued contact of o-bromophenol with a strong acid.
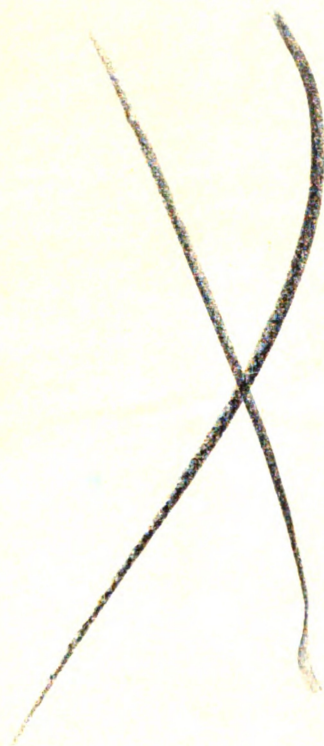
SUMMARY

1. Tertiary amyl and tertiary butyl alcohols condensed with ortho-chlorophenol at room temperature, in the presence of aluminum chloride, to give fifty per cent yields of the corresponding para-tertiary-alkyl-ortho-chlorophenols

2. Tertiary butyl alcohol and tertiary amyl alcohol both failed to condense with para-chlorophenol, either at room temperature or at 60° C.

3. Tertiary amyl and tertiary butyl alcohols reacted with ortho-bromophenol, in the presence of aluminum chloride, to give, mainly, the corresponding para-tertiary-alkyl-phenol. Small amounts of the para-tertiary-alkyl-ortho-bromophenols were recovered, together with unidentified products.

1. Huston, R. C. and W. R. Coleman, Master's Thesis, Michigan State College, (1937).

2. Perrier, G., Ber., 29, 173, (1896).

3. von Dumreicher, O., Ber., 15, 1866, (1882).

4. Leroy, A. J., Bull. soc. chim., 43, 210, (1887).

5. Kuhn, M. and N. L. Muller, Monatsch, 30, 407, (1909).

6. Kuhn, M. and F. Bum, Monatsch, 33, 923, (1912).

7. Kuhn, M., Monatsch, 58, 108, (1931).

8. Salkind, J. and Z. Stetzuro, Ber., 64, 953, (1931).

9. Lohfert, H., Ber., 63, 1939, (1930).

10. Copisarow, M., J. Chem. Soc., 119, 442, (1921).

11. Perry, T. M. and E. E. Reid, J. Am. Chem. Soc., 49, 3146, (1927).

12. Bruce, W. F. and F. Todd, J. Am. Chem. Soc., 61, 158, (1939).

13. Suter, C. M., E. J. Lawson and P. G. Smith, J. Am. Chem. Soc., 61, 161, (1939).

14. Weston, A. W. and C. M. Suter, J. Am. Chem. Soc., 61, 2356, (1939).

15. Henne, A. L. and M. S. Newman, J. Am. Chem. Soc., 60, 1697, (1938).

16. Norris, J. F. and H. S. Turner, J. Am. Chem. Soc., 61, 2128, (1939).

17. Ipatieff, V. N. and B. B. Corson, J. Am. Chem. Soc., 59, 1417, (1937).

18. Orlov, N. N. and P. G. Vaisfeld, C. A., 31, 7043, (1937).

19. Nightingale, Dorothy V., Chem. Rev., 25, 329, (1939).

20. Jackson, C. L. and F. L. Dunlap, Am. Chem. J., 18, 118, (1896).

21. Baichikov, A. G. and A. G. Ladbrodkin, C. A., 28, 4544, (1934).

22. Raiford, L. C. and F. W. Heyl, Am. Chem. J., <u>43</u>, 393, (1910).

23. Raiford, L. C. and F. W. Heyl, Am. Cher. J., <u>44</u>, 209, (1910).

24. Raiford, L. C. and A. L. LeRosen, J. Am. Chem. Soc., <u>66</u>, 1872, (1944).

25. Raiford, L. C. and G. R. Miller, J. Am. Chem. Soc., <u>55</u>, 2125, (1933).

26. Amerson, W. S., F. B. Dorf, and A. J. Deutschamn, J. Am. Chem. Soc., <u>62</u>, 2159, (1940).

27. Hodgson, H. H. and J. Nixon, J. Am. Chem. Soc., <u>133</u>, 2272, (1931).

28. Huston, R. C. and G. W. Warren, Master's Thesis, Michigan State College, (1931).

29. Huston, . C. and R. L. Guile, Master's Thesis Michigan State College, (1933).

30. Huston, R. C. and H. M. D'Arcy, Master's Thesis, Michigan State College, (1930).

31. Huston, R. C. and B. L. Fayerweather, Master's Thesis, Michigan State College, (1931).

32. Huston, R. C. and A. H. Neeley, Master's Thesis, Michigan State College, (1933).

33. Huston, R. C. and H. W. Strickler, J. Am. Chem. Soc., <u>55</u>, 4317, (1933).

34. Huston, R. C. and E. F. Eldridge, J. Am. Chem. Soc., <u>53</u>, 2260, (1931).

35. Klarmann, E., V. A. Shternov, and L. W. Cates, J. Am. Chem. Soc., <u>55</u>, 2576, (1933).

36. Mills, L. E., U. S. Pat., 2,176,010, (Oct. 10, 1939).
    C. A., <u>34</u>, 858, (1940).
    U. S. Pat., 2,221,807, (Nov. 19, 1940).
    C. A., <u>35</u>, 1936, (1941).

37. Klarmann, E., L. W. Gates, V. A. Shternov, and P. H. Cox, J. Am. Chem. Soc., <u>55</u>, 4661, (1933).

38. Dains, F. B. and I. R. Rothrock, Am. Chem. J., <u>17</u>, 113, (1895).

39. Huston, R. C. and A. H. Neeley, J. Am. Chem. Soc., **57**, 2176, (1935).

40. Young, S. and L. C. Fortey, J. Chem. Soc., **81**, 729, (1902).

41. Ayres, E. A., Ind. Eng. Chem., **21**, 906, (1929).

42. Kohlleben, W. J., Ber., **42**, 4370, (1909).

43. Huston, R. C. and A. H. Arett, Master's Thesis, Michigan State College, (1938).

44. Chattaway, F. D., J. Chem. Soc., **133**, 2495, (1931).

45. Fischer, B. and B. Crutzner, Ber., **26**, 1643, (1893).

46. Shriner, R. L. and R. C. Fuson, The Systematic Identification of Organic Compounds, John Wiley and Sons, Inc., New York, 1940, page 133.

47. DeCrauw, T., Rec. trav. chim., **50**, 753, (1931).

48. Price, C. C., Chem. Rev., **29**, 37, (1941).