REACTIONS OF POLYHALOGENATED AROMATIC COMPOUNDS

AND RELATED ETHERS WITH METAL/AMMONIA SOLUTIONS


by


Stephen R. Cater, B.Sc.(Hons.)


A Thesis

submitted to the Department of Chemistry

in partial fulfilment of the requirements

for the degree of

Master of Science


August 1982

Brock University

St. Catharines, Ontario

## Abstract

This work contains the results of a series of reduction studies on polyhalogenated aromatic compounds and related ethers using alkali metals in liquid ammonia.

In general, polychlorobenzenes were reduced to the parent aromatic hydrocarbon or to 1,4-cyclohexadiene, and diphenylethers were cleaved to the aromatic hydrocarbon and a phenol. Chlorinated diphenylethers were reductively dechlorinated in the process. For example, 4-chlorodiphenyl-ether gave benzene and phenol.

Pentachlorobenzene and certain tetrachlorobenzenes disproportionated to a fair degree during the reduction process if no added proton source was present. The disproportionation was attributed to a build-up of amide ion. Addition of ethanol completely suppressed the formation of any disproportionation products.

In the reductions of certain diphenylethers, the reduction of one or both of the diphenylether rings occurred, along with the normal cleavage. This was more prevalent when lithium was the metal used.

As a sidelight, certain chlorophenols were readily dechlorinated.

In light of these results, the reductive detoxification of the chlorinated dibenzo-1,4-dioxins seems possible with alkali metals in liquid ammonia.

## Acknowledgements

The author would like to express his appreciation to Dr. M. S. Gibson for his guidance, helpful discussions and suggestions throughout the course of this work.

The help of Mr. Timothy Jones in obtaining the mass spectra is greatly appreciated.

The technical staff at Brock University are to be commended for the help which they have given the author.

Finally, the fellow students at Brock University are to be acknowledged for helping to create a good atmosphere at the university.

## Table of Contents

# List of Figures

# List of Tables

# Introduction

## Part I: Environmental Considerations

Polyhalogenated aromatic compounds have received a great deal of interest over the past several years. Members of this class of compound include substituted chlorobenzenes, chlorophenols, poly-chlorinated aromatic pesticides, polychlorinated and polybrominated biphenyls, polychlorinated diphenylethers, polychlorodibenzofurans and polychlorodibenzo-1,4-dioxins. These compounds have a wide variety of industrial and agricultural uses and some, such as the polychlorinated dibenzofurans and dibenzo-1,4-dioxins have no known worthwhile purposes. Chlorobenzenes and chlorophenols are used as solvents or as starting materials for a wide variety of chemical processes.[1] Pentachlorophenol has found extensive use as a pesticide.[2] A major use for polychlorinated aromatic compounds is as pesticides. As of 1974, there were over seventy-five polychlorinated aromatic pesticides on the market[3] and examples include 2,2-bis(p-chlorophenyl)-1,1,1-trichloroethane (DDT), 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Polychlorinated biphenyls (PCBs) and to a lesser extent polybrominated biphenyls have been widely used as electrical insulators in closed capacitors and in the manufacture of various paints and resins.[3] Polychlorinated diphenyl-ethers have been used as herbicides[4] and as electrical insulators[5] where,

in the latter case, they have been used as replacements for the poly-
halogenated biphenyls.[6] Polychlorodibenzofurans and polychlorodibenzo-
1,4-dioxins, while possessing no known practical uses, have become
extremely important classes of compounds and have received a great
amount of research recently. The reasons for this will be discussed
shortly.

The structures of the major classes of polyhalogenated aromatic
compounds of current interest are given in Figure 1. These compounds
are environmentally important because their extensive use over the
past several years has led to their accumulation in the environment.
There is a concern over the toxic effects which these compounds have
shown to plant, animal and human life. This has led to research into
methods of degradation and detoxification of many of these classes of
compounds. Much of this research has been focused on two classes of
compounds recently. These are the polychlorodibenzofurans and the
polychlorodibenzo-1,4-dioxins. As stated previously, these compounds
have no known practical uses, but they are found as impurities in
technical preparations of certain chlorophenols,[7] in 2,4,5-T mixtures,[7]
in polychlorinated biphenyls,[8] and in the pyrolysis products of chloro-
benzenes.[1]

Much of the research into these two classes of compounds has
focussed on 2,3,7,8-tetrachlorodibenzo-1,4-dioxin (TCDD). This
compound has been found to be extremely toxic and it exhibits chronic
carcinogenic, mutagenic and teratogenic effects.[8] It is quite stable
to heat, acids and alkalies and does not thermally decompose until

2,4-D

2,4,5-T

Polychlorobiphenyls(PCBs)

Polychlorodiphenylethers

Polychlorodibenzofurans

Polychlorodibenzo-1,4-dioxins

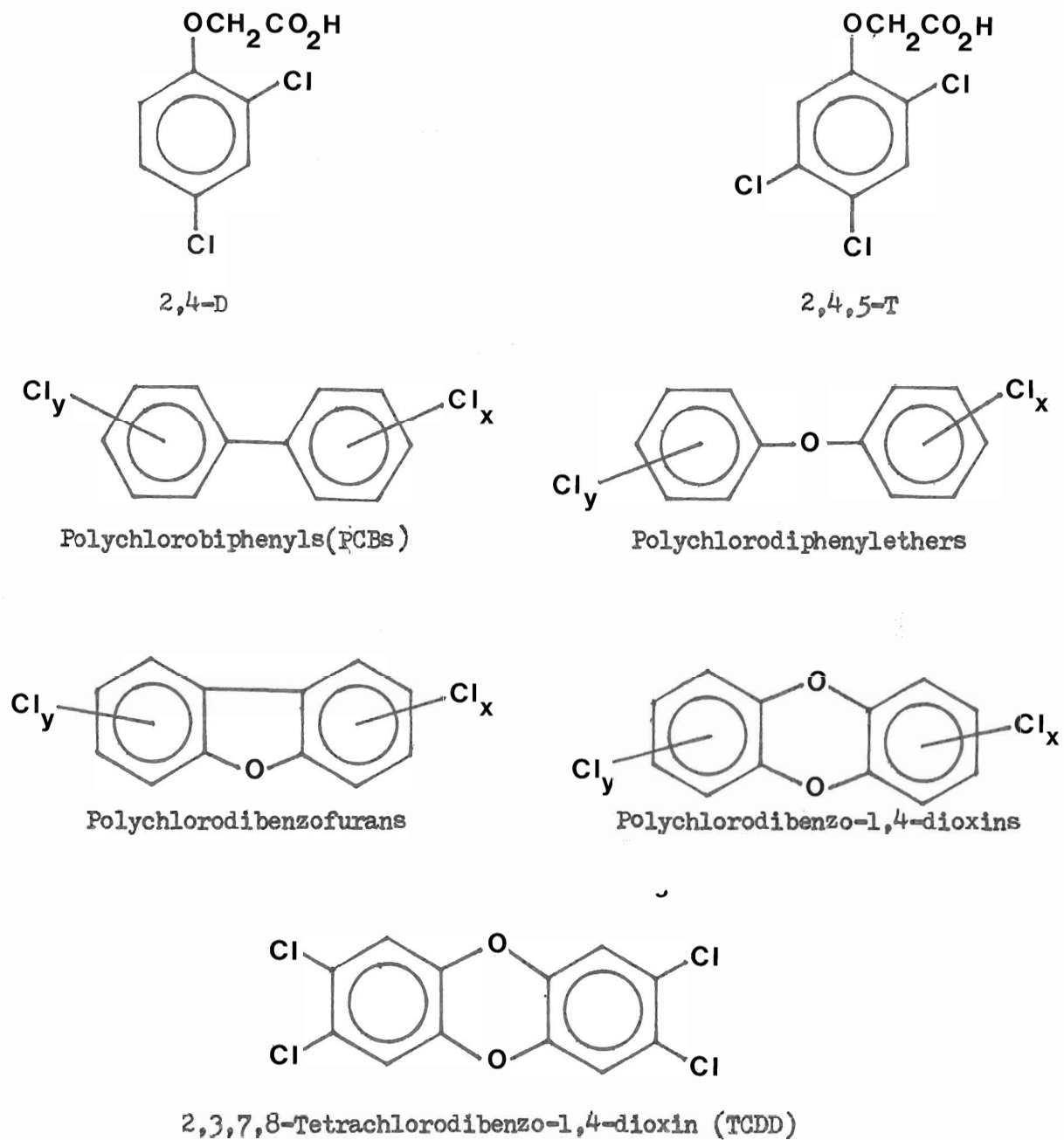2,3,7,8-Tetrachlorodibenzo-1,4-dioxin (TCDD)

Figure 1: Structures of Polyhalogenated Aromatic Compounds of Current Environmental Interest

about 800 °C.[9]  The toxic effects of TCDD have been well documented[7,10]
and there is now a great concern about its effect in the environment.
TCDD is toxic at the parts-per-billion to parts-per-trillion level.[10]
There have been numerous reports of accidents resulting from the
exposure of humans and animals to TCDD.[7,10]  These accidents resulted
in high stillbirth rates among humans, killed many animals and sent
many people to hospital for treatment of poisoning.  The growing
evidence of TCDD accidents and poisoning caused by TCDD and other
chlorinated dibenzo-1,4-dioxins and dibenzofurans make the degradation
and detoxification of these compounds an important research area at the
present time.

The fact that these compounds are quite stable makes degradation
a difficult and expensive chore.  The stability of TCDD has already
been noted.  One of the major reasons for the widespread use of PCBs
can be attributed to their relative stability.  The problem is more
severe for the chlorinated dibenzo-1,4-dioxins and dibenzofurans since
these compounds are generally more thermally stable than the PCBs.

There have been four proposed general methods for the degradation
of TCDD.  These are incineration, chlorinolysis, soil biodegradation
and photodecomposition.[11]  These methods are also applicable to the
degradation of other halogenated compounds such as the polychlorinated
dibenzofurans and the PCBs.

Incineration requires very high temperatures ($\sim 1000$ °C) to
decompose TCDD.  This makes design considerations a problem and
imposes high costs to the incineration process.  There is some debate

on the effeciency of this method and one author has reported that
current technology ( in 1980 ) is inadequate to reduce the levels of
halogenated pollutants from one part-per-million to one part-per-
billion,[12] levels which would be quite inadequate for TCDD detoxi-
fication. Another problem with incineration as a method for degradation
of halogenated organic pollutants is that many halogenated compounds
form small amounts of halogenated dibenzofurans and dibenzo-1,4-dioxins
when thermally degraded. A controversial theory from Dow Chemicals
states that polychlorinated dibenzo-1,4-dioxins, dibenzofurans and
biphenyls are formed in trace amounts from all sorts of combustion
such as automobiles, fireplaces and cigarettes.[7,10] There is also
the problem that traces of the chlorinated dibenzo-1,4-dioxins and
dibenzofurans may escape with the stack gases during combustion and
thus could become widely distributed in the environment. One report
states that chlorinated dibenzo-1,4-dioxins were detected in the gases
from combustion of precursors such as polychlorophenols.[13] These
varied problems make incineration a controversial and up to now an
inadequate method of degradation and detoxification of TCDD and other
polyhalogenated aromatic compounds.

Chlorinolysis involves the use of high chlorine pressures and
temperatures to convert organic compounds into carbon tetrachloride.[11]
This is a very drastic, destructive and expensive process and has not
received much attention in the literature. It will not be commented
on any further in this thesis as it does not seem to be a good method
for the destruction of polyhalogenated aromatic compounds.

Soil biodegradation is only feasible for cultivable soils, but it is reported that TCDD is not readily degraded in soil.[14] TCDD is also not very mobile in soil and thus the soil acts like an unreactive storage container for TCDD. The half-life of TCDD in soil has been estimated as up to ten years in length.[15] It seems unlikely that the method of soil biodegradation is a feasible process for TCDD degradation.

Photodecomposition is a promising method of degradation and has received considerable attention in the past few years. TCDD can be photochemically reduced under initiation by ultra-violet light. The initial product is 2,3,7-trichlorodibenzo-1,4-dioxin[7] followed by formation of dibenzo-1,4-dioxin and finally 2-hydroxydiphenylether.[14] An organic solvent is required for decomposition in a reasonable length of time and the time required for total photodecomposition varies between four and eighteen hours depending upon the solvent used.[12] Photodecomposition has been used on other halogenated aromatic compounds such as PCBs.[16] These other studies have resulted in the realization that photolysis of some chlorinated compounds can lead to formation of polychlorinated dibenzo-1,4-dioxins and dibenzofurans. Examples include the formation of octachlorodibenzo-1,4-dioxin from the photolysis of pentachlorophenol[17] and the formation of polychloro-dibenzofurans from irradiation of chlorinated diphenylethers.[18] These results indicate that there may be some problems in attempts to use photodecomposition as a general method for the destruction of many

types of polyhalogenated pollutants, although it may be attractive
for TCDD destruction.

In the past two or three years there have been some new methods
proposed and developed for the destruction of various polyhalogenated
aromatic compounds. These are chemical methods and usually involve
a reduction of some type. They have been almost exclusively applied
to the destruction of the PCBs by dechlorination. Examples include
the use of a catalytically activated metal powder to reduce chloro-
benzene, chlorinated phenoxyacetic acid derivatives and PCBs;[19]
the destruction of PCBs with a sodium particle dispersion in hydro-
carbon oil;[20] the dechlorination of PCBs by sodium in polyethylene-
glycol;[21] and the electrochemical degradation of polychlorinated dibenzo-
1,4-dioxins and PCBs across platinum electrodes.[22] A method which is
more applicable to this work has been the use of sodium naphthalenide
in tetrahydrofuran to dechlorinate PCBs.[23,24] Sodium naphthalenide
is almost as powerful a reducing agent as the alkali metals themselves[25]
and can donate electrons to the PCBs, resulting in loss of chloride ions
and generation of a radical from the PCB moiety. There was no proton
source available in these studies so polymeric products were obtained
from coupling of aromatic radicals. This procedure has also been used
on the monohalogenated benzenes where the products obtained were
benzene, biphenyl and terphenyls.[26]

A somewhat related method for the reduction of PCBs involves
reduction initiated by ultra-violet light with sodium borohydride.[27]

The PCBs were activated by the ultra-violet light, losing a

chlorine radical in each step to give an aromatic radical which then abstracted a hydrogen from the borohydride. This method has also been applied to the monohalogenated benzenes and gave quantitative yields of benzene.[28] In this work, iodobenzene was also reduced by sodium in liquid ammonia using sodium borohydride as a hydrogen source.

These past few results are certainly encouraging for PCB degradation and some patents have been taken out on these processes.[20,21,22]

Their utilization in TCDD and other halogenated pollutant degradation has not been established however and thus there seems to be lacking a good general method for the degradation and detoxification of TCDD and other polyhalogenated aromatic compounds that is safe, efficient, reliable and rather inexpensive.

The work in this thesis is related to trying to find and develop such a method of degradation. The method chosen is reaction with solutions of alkali metals in liquid ammonia. The reasons for choosing this method will be given in the second part of this introduction, although precedents have been established with somewhat related methods such as the use of sodium naphthalenide and the use of sodium in polyethyleneglycol. These last two methods were tested on the PCBs so their use as general methods has not been determined. It is hoped from this work that the reactions of a variety of halogenated aromatic compounds with solutions of alkali metals in liquid ammonia will efficiently produce compounds of lower halogen content or compounds containing no halogens. The removal of halogens in lowering of the

toxicity of the halogenated pollutants is significant. Looking at
the dibenzo-1,4-dioxins, the nonhalogenated dibenzo-1,4-dioxin is
low in toxicity, whereas the chlorinated dibenzo-1,4-dioxins have a
wide range of toxicities.[7] Table 1 gives the relative toxicities
of a variety of dibenzo-1,4-dioxins.[10]

From Table 1, it is seen that 2,3,7,8-tetrachlorodibenzo-1,4-
dioxin (TCDD) is the most toxic isomer towards guinea pigs. Generally,
lowering the chlorine content lowers the toxicity, although the
position of the chlorines is also important towards toxicity. It
has been found that the 2,3,7 and 8 positions of the dibenzo-1,4-
dioxins, when chlorinated, give the most toxic isomers. This is
related to the metabolism of these compounds, where it is proposed
that the 2,3,7,8- isomers can form highly reactive epoxides of the
general structure (I).[29]
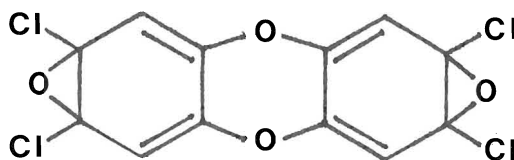


(I)

Isomers of the dibenzo-1,4-dioxins which do not have chlorines
at the 2,3,7 and 8 positions form epoxides which are not as reactive.
This results in a lower toxicity for these dibenzo-1,4-dioxins when
compared to isomers which have chlorines at the 2,3,7 and 8 positions.
Thus, from a standpoint of detoxification, dechlorination is very
important and should produce compounds which are much safer to handle

| Dioxin Isomer | $LD_{50}$( g/kg) for Guinea Pig |
|---|---|
| 2,8 | 300,000 |
| 2,3,7 | 29,000 |
| 2,3,7,8 | 1 |
| 1,2,3,7,8 | 3 |
| 1,2,4,7,8 | 1,125 |
| 1,2,3,4,7,8 | 73 |
| 1,2,3,6,7,8 | 100 |

Table 1: Relative Toxicities of Chlorinated Dibenzo-1,4-dioxins

and dispose of than the original chlorinated dibenzo-1,4-dioxin. This should be applicable to most types of halogenated aromatic compounds and hence is environmentally important from a standpoint of detoxification of these compounds.

# Introduction

## Part II: Reductions by Solutions of Alkali Metals in Liquid Ammonia

The reduction of compounds by solutions of an alkali metal, usually sodium or lithium, in liquid ammonia normally with an added proton source such as an alcohol is usually referred to as the Birch reduction. It is an important type of reduction in that it is very powerful and yet can be quite selective depending upon the substrate and conditions employed. Birch has been the pioneer in this reduction but the groundwork was laid by Wooster[30] who observed in 1937 that when benzene was added to sodium and ethanol in liquid ammonia, 1,4-cyclohexadiene was formed. This partial reduction of an aromatic ring is an important focus of the Birch reduction.

Alkali metals dissolve in liquid ammonia to give deep blue solutions. These solutions can be thought of as metal cations and solvated electrons.[31] The blue colour is characteristic of all of the alkali and alkaline-earth metals in liquid ammonia and is caused by an intense absorption of the solvated electrons.[32] These solvated electrons are very chemically reative and will reduce a wide variety of substrates. An important reaction is the addition of electrons to conjugated $\pi$ systems such as aromatic rings. This results in the conversion of aromatic compounds into dihydro-derivatives. This was first discovered by Wooster[30] and later developed more fully by Birch.[31,33,34] The mechanism of the reduction has been widely studied

and has been shown to proceed via radical and radical-anion inter-
mediates.[35] Scheme 1 gives the general mechanism for the reduction
of an aromatic ring (Ar).

$$M\cdot + NH_3 \rightleftharpoons M^+ + e_s^-$$

$$Ar + e_s^- \rightleftharpoons [Ar^{\overline{\cdot}}] \qquad \text{-----(1)}$$

$$[Ar^{\overline{\cdot}}] + e_s^- \rightleftharpoons [Ar]^{-2} \qquad \text{-----(2)}$$

$$\downarrow NH_3$$

$$[ArH]^- + NH_2^-$$

$$[Ar^{\overline{\cdot}}] + ROH \rightleftharpoons [ArH\cdot] + RO^- \qquad \text{-----(3)}$$

$$[ArH\cdot] + e_s^- \rightleftharpoons [ArH]^- \xrightarrow{ROH} ArH_2 + RO^-$$

Scheme 1

The first step in Scheme 1 is formation of a solvated electron
from dissolution of an alkali metal (M·). The solvated electron then
reacts with the aromatic substrate to give an intermediate radical-
anion ($Ar^{\overline{\cdot}}$), as shown in equation 1. This initial equilibrium
usually lies to the left due primarily to the stability of the

aromatic ring.  The fate of the radical-anion is determined by whether an added proton source is present in the reaction mixture.  If no added proton source is present then the radical-anion is attacked by a second solvated electron since ammonia is not acidic enough to protonate the radical-anion.  The resulting doubly charged anion, generated in equation 2 is then sufficiently basic to be protonated by ammonia to give the aromatic anion (ArH$^-$) and an amide ion.  Clearly, as the reduction proceeds therefore, the concentration of the amide ion will increase which can result in secondary processes occuring.  This will be further discussed shortly.  The aromatic anion (ArH$^-$) is then subsequently protonated to give the hydrocarbon ArH$_2$ during the work-up, usually upon addition of ammonium chloride or water.

The presence of an added proton source, such as an alcohol, in the reaction mixture alters the course of the reduction.  The intermediate radical-anion (Ar$^-$) is protonated by the alcohol to give the aromatic radical (ArH$^{\cdot}$) in equation 3.  This radical is then attacked by a second solvated electron to give the aromatic anion (ArH$^-$) which is subsequently protonated by the alcohol to give the dihydro-derivative of the aromatic substrate.

The structures of the dihydro-derivatives obtained depend upon two factors.  The first is due to the fact that in the intermediate radical-anion, the radical and the lone pair of electrons will tend to repel each other and hence will end up in positions para to each other.  This results in non-conjugated double bonds in the resulting dihydro-derivatives.  The structural representation of the radical-

anion can be shown, in the case of the reduction of benzene, as (II).



(II)
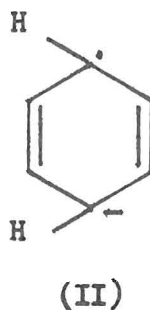
Subsequent protonation would give a radical which would again be attacked by a solvated electron followed by protonation to form the 1,4-dihydroderivative. In the case of (II), this would lead to 1,4-cyclohexadiene, which is the reduction product of benzene.

The second factor determining the structure of the product is due to the electronic effects of the substituents on the aromatic ring. Electron donating groups, such as a methyl or a methoxyl group, give 2,5-dihydro-derivatives since the electrons will be repulsed by the substituent. Conversely, electron attracting groups, such as a carboxylic acid group, give 1,4-dihydro-derivatives. The structures of the products obtained from the reductions of anisole, which contains the electron repelling methoxyl group, and benzoic acid, which contains an electron attracting group, are shown in the mechanisms given in Schemes 2 and 3 respectively.[36]

In Scheme 2, the first proton adds to the meta position, since this position would have the greatest electron density in the initial radical-
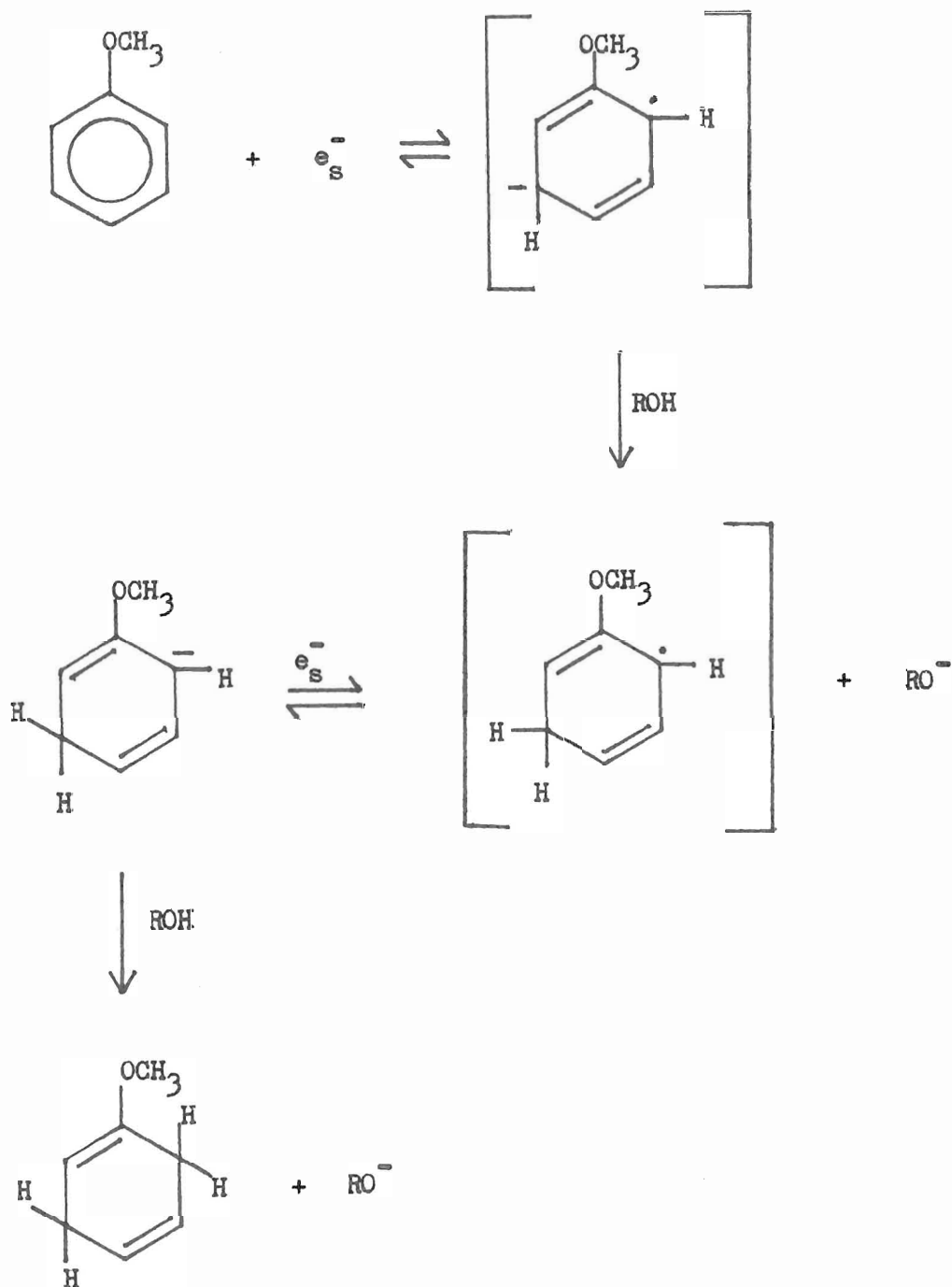
Scheme 2
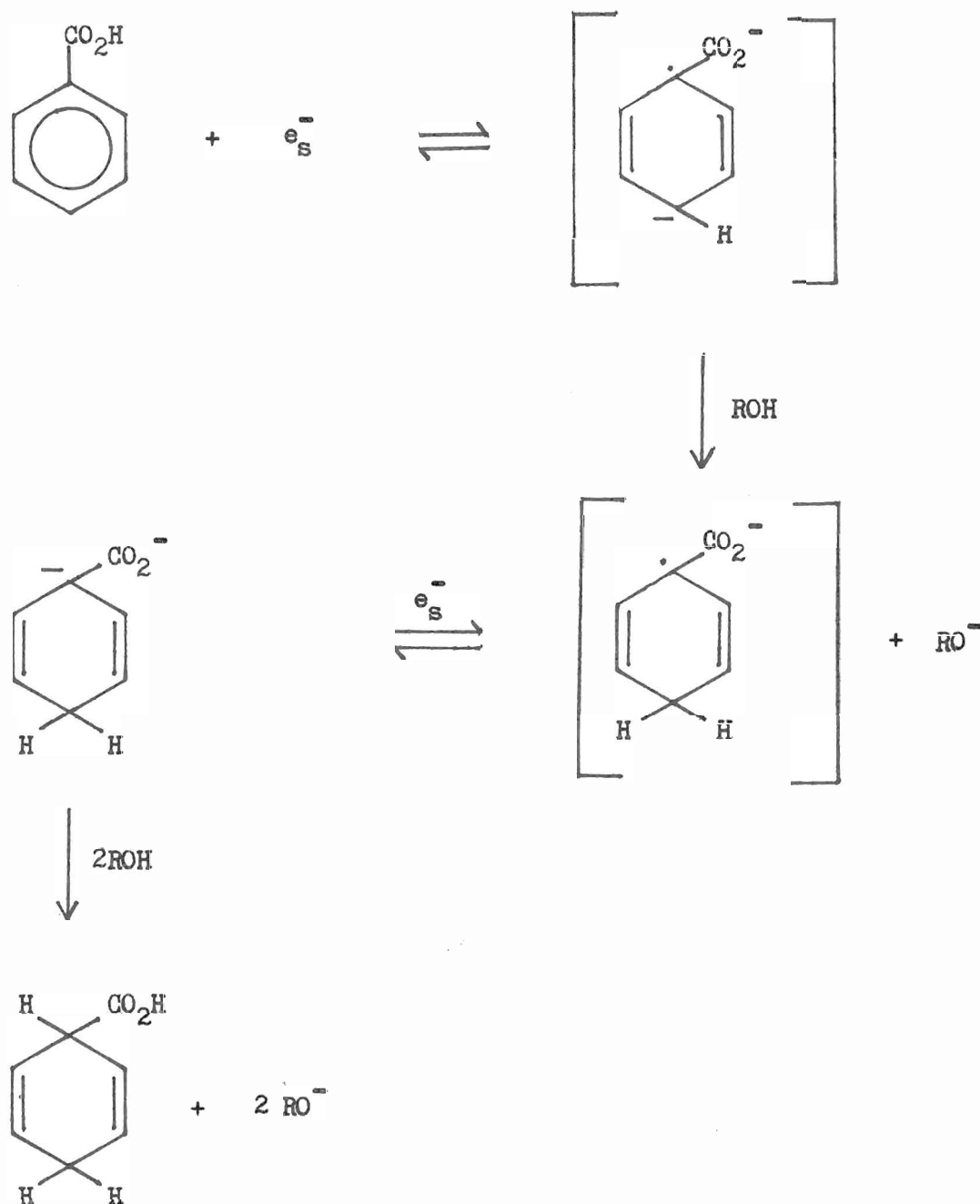
Scheme 3

anion that is formed, due to repulsion of the lone pair of electrons by the methoxyl group. The reaction then proceeds as shown to give 2,5-dihydroanisole.

A problem arises from Scheme 3 when looking at the reduction of benzoic acids. There is a question as to whether the reacting species is the acid or the acid salt. It has been found experimentally that benzoic acids are more rapidly reduced than benzene under Birch conditions.[37] The acid group thus acts as an electron attracting group and hence speeds up the reduction process. A carboxylate group, by nature of its negative charge, would not be as strongly electron attracting and hence should react slower, if at all, compared to the acid under Birch conditions. Under the alkaline conditions of the reaction, the benzoic acid should form its salt. It is conceivable that an equilibrium is established as given in equation (4).

$$PhCO_2^- + NH_3 \rightleftharpoons PhCO_2H + NH_2^- \qquad\qquad \text{-----(4)}$$

Ammonia is present in a large excess which would force the equilibrium to the right. Thus, there may be a considerable concentration of the acid present. If the acid then reacted with the sodium, the equilibrium in equation (4) would shift to produce more of the acid which could then react.

The Birch reduction has been applied to a wide variety of aromatic compounds with substituents such as methyl, methoxyl, carboxyl and amino.[31] There has not been, however, a great deal of work done on

halogenated compounds. This is somewhat surprising since the reaction of sodium with organic halides has been known for well over one hundred years, and has been used as a quantitive method for determining the amount of halogens present in organic halides.[38] An early use of alkali metals with organic halides was the Wurtz and Wurtz-Fittig dimerizations of organic halides. The general reaction is shown in equation (5).[38]

$$2 \text{ RX } + \text{ 2 Na } \longrightarrow \text{ R-R } + \text{ 2 NaX} \qquad \text{-----}(5)$$

The literature on metal/ammonia reactions of organic halides is not very extensive however. The monohalogenated benzenes have been extensively studied.[39,40] The major products obtained were benzene, and in the case where no proton source was added, aniline, diphenylamine and triphenylamine. 1,2-Dichlorobenzene has been reduced by sodium in liquid ammonia to give benzene and 1,2-diaminobenzene.[41] A second study on all the dichlorobenzenes gave aniline and benzene in all cases and 1,3-diamminobenzene from the reduction of 1,3-dichlorobenzene.[42] 2-Chloro- and 4-chlorotoluene have been reduced to give benzene along with 2-amino- or 4-aminotoluene respectively.[41] Reduction of 1-bromonaphthalene with sodium in liquid ammonia gave naphthalene.[41] There are no reported results where any different aromatic halides have been reduced by solutions of alkali metals in liquid ammonia.

One notable result has been the dehalogenation of 4-bromo- and 2-chlororanisole by calcium hexammine. Birch[43] noted that the presence

of the halogen increased the reduction of these substituted anisoles over anisole, but he did not investigate this any further, nor did he try the reductions with sodium or lithium in liquid ammonia.

The reductive fission of a group from an aromatic ring during metal/ammonia reduction is not restricted to the halides. Reductive fission can occur with various carbon-oxygen bonds, carbon-sulphur bonds and even certain carbon-carbon bonds.[31] The important case to consider in relation to this work is the fission of the carbon-oxygen bonds of diphenylethers. The significance of this lies in the fact that the dibenzo-1,4-dioxins contain diphenylether linkages.
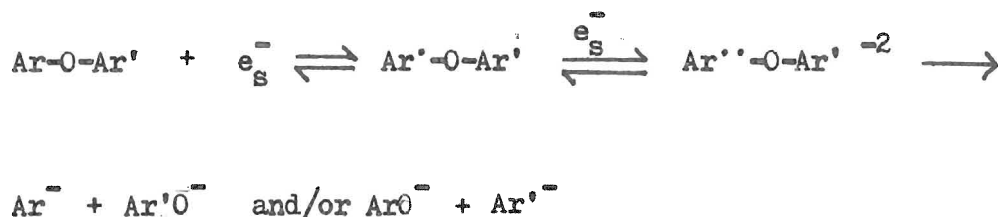
It has been found that diphenylethers are generally readily cleaved by sodium in liquid ammonia. Sartoretto and Sowa[44] studied the cleavage of a variety of methyl, methoxyl, amino and carboxyl substituted diphenylethers. They found that the course of cleavage was determined by the stabilizing effects of a substituent on the carbanion (R$^-$) and not on the corresponding phenoxide ion. The general reaction is given in equation (6).

$$ROR' \longrightarrow RH + R'OH + ROH + R'H \qquad \text{-----(6)}$$

If (R) contains an electron attracting group then the major products are RH and R'OH and not ROH and R'H since (R$^-$) would be stabilized by the electron attracting group. Conversely, if (R) contains an electron donating group then R'H and ROH are the major cleavage products. Examples of this preferential cleavage are seen

in the cleavage of 4-carboxydiphenylether to give 100% phenol plus benzoic acid, and in the cleavage of 4-methoxydiphenylether to give 81% 4-methoxyphenol plus benzene and 19% phenol plus anisole. The resonance effect of a substituent is more effective than the inductive effect. It was also found that a substituent is more effective in the para position than in the ortho and meta positions.

The mechanism of the cleavage reaction has been studied by electron spin resonance spectroscopy.[45] Studies indicated that the cleavage occurred from the dianion which leads to the mechanism of Scheme 4 for the cleavage of diphenylethers by sodium in liquid ammonia.

$$Ar\text{-}O\text{-}Ar' \; + \; e_s^- \; \rightleftharpoons \; Ar^{\cdot}\text{-}O\text{-}Ar' \; \xrightarrow{e_s^-} \; Ar^{\cdot\cdot}\text{-}O\text{-}Ar'^{\,-2} \; \longrightarrow$$

$$Ar^- \; + \; Ar'O^- \quad and/or \quad ArO^- \; + \; Ar'^-$$

### Scheme 4

The order of reactivity of the alkali metals was found to be: lithium < sodium < potassium < rubidium < cesium.

An important application of the cleavage of diphenylethers with sodium in liquid ammonia has been in the determination of the structures of the bisbenzylisoquinoline alkaloids.[46] These alkaloids contain one or more diphenylether linkages which are readily cleaved by solutions of sodium in liquid ammonia. Alkaloids containing the dibenzo-1,4-dioxin group have also been cleaved. Figure 2 gives two examples.
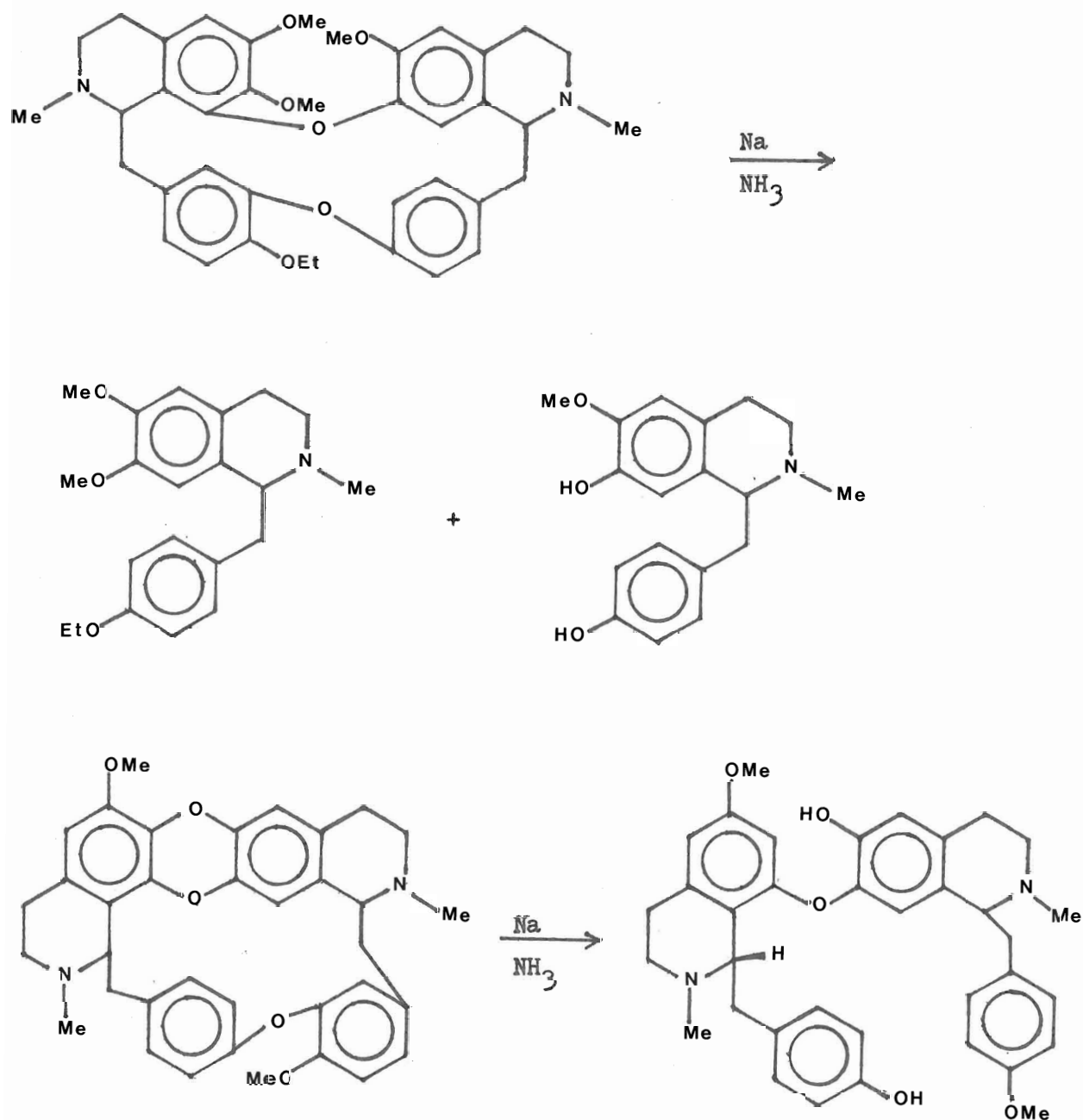
Figure 2: Cleavages of Alkaloids by Sodium in Liquid Ammonia.

The cleavages of a number of dibenzo-1,4-dioxins with sodium in liquid ammonia have also been studied. Dibenzo-1,4-dioxin gave 2-hydroxydiphenylether as the sole product from cleavage with sodium in liquid ammonia.[47] The cleavages of a variety of methyl and methoxyl substituted dibenzo-1,4-dioxins have also been studied. The direction of cleavage is similar to that obtained for the substituted diphenylethers and as a representative example 1,6-dimethyldibenzo-1,4-dioxin (III) gave a mixture of 2',3-dimethyl-2-hydroxydiphenylether (IV) and 2,3'-dimethyl-6-hydroxydiphenylether (V).[48]
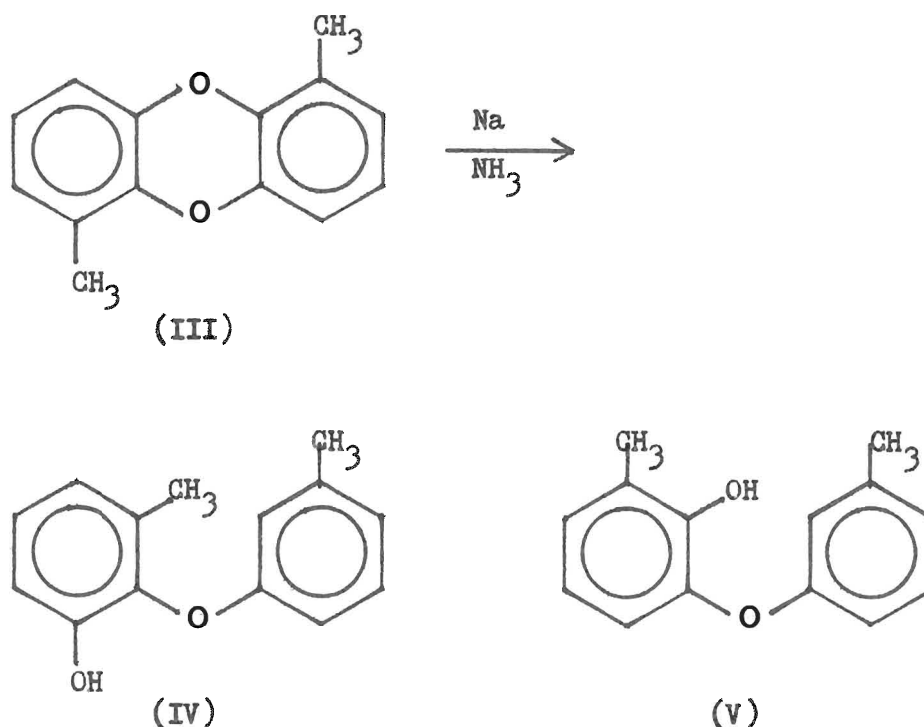


The cleavage of dibenzo-1,4-dioxin with lithium in tetrahydrofuran gave similar results as the cleavage with sodium in liquid

ammonia.[49] The cleavage of dibenzofuran with lithium in tetrahydro-
furan was also performed and gave 2-hydroxybiphenyl.[49]

The reactions of halogenated diphenylethers, dibenzo-1,4-dioxins
and dibenzofurans with metal/ammonia solutions have not been reported.
There has been some limited work on other reactions of halogenated
diphenylethers. Huang[50,51] has studied the cleavage of 2-, 3- and
4-chlorodiphenylether and 4-chloro-4'-methyldiphenylether with n-butyl-
magnesium bromide in the presence of cobaltous chloride. He did not
observe dechlorination as he hoped, but got complex mixtures of
products. 4-chlorodiphenylether gave, for example, a mixture of
tribromophenol, 4-chlorophenyl benzoate, 4-chlorophenoxyacetic acid,
benzene and large amounts of unreacted starting material. Langham
and co-workers[52] have studied the reactions of halogenated diphenyl-
ethers such as 4-chlorodiphenylether with lithium alkyls. 4-Chloro-
diphenylether gave, after carbonation of the anions, a 14-36% yield
of 5-chloro-2-phenoxybenzoic acid and the reaction rate for different
halogens was found to be iodine > bromine >> chlorine. These last two
studies are inadequate for dechlorination of chlorinated aromatic
pollutants.

In a somewhat related study, a dechlorinated derivative of 4-chloro-
diphenylether has been produced by treatment with sodium and toluene
in the presence of trimethylsilyl chloride to give a 59% yield of
4-trimethylsilyldiphenylether.[53]

In a different vein, there has been some limited work on the
degradation of chlorinated diphenylethers initiated by ultra-violet

light.[54] 4-Chlorodiphenylether gave a 38% conversion to diphenylether after 88 hours of exposure to ultra-violet light. 3,3',4,4'-Tetra-chlorodiphenylether on exposure to ultra-violet light gave a 44% conversion to a mixture of 3,4,4'-trichlorodiphenylether, 3,3',4-trichlorodiphenylether and 4,4'-dichlorodiphenylether. One problem with this method for the removal of chlorines from diphenylethers is that for diphenylethers with ortho-substituted chlorines, dibenzo-furans were formed in about 10% yields. For example, 2,4-dichloro-diphenylether gave a 35% conversion to 4-chlorodiphenylether and 2-chlorodibenzofuran.

The reactions of halogenated compounds with metal/ammonia solutions therefore, have not been extensively studied. The reactions of the polychlorobenzenes with sodium in liquid ammonia were studied by this author during a B.Sc.(Hons.) project.[55] Reduction was observed to some degree for all of the polychlorobenzenes. The ratio of sodium to starting material was kept at two to one in all cases so that the course of the reactions could be studied. This resulted in a large amount of secondary processes occurring, such as substitution and disproportionation. Aniline derivatives were formed in cases where there was no added proton source in the reaction mixture. Their formation was most likely caused by a buildup of amide ion during the reduction process. Cases where ethanol was added as a proton source frequently gave ethoxybenzene as a product, but suppressed any aniline formation or disproportionation occurrance. The disproportionation occurred for the reactions of 1,2,3,4- and 1,2,3,5-tetrachlorobenzene

and of pentachlorobenzene with sodium in liquid ammonia with no added ethanol. 1,2,3,4-Tetrachlorobenzene gave a mixture of 1,2,4-trichlorobenzene and pentachlorobenzene; 1,2,3,5-tetrachlorobenzene gave 1,3,5-trichlorobenzene and pentachlorobenzene; and pentachlorobenzene gave 1,2,3,5- and/or 1,2,4,5-tetrachlorobenzene and hexachlorobenzene as the products of disproportionation. This phenomenon of base induced disproportionation of polyhalogeno-benzenes has been studied by Bunnett[56] and coupled with further work on the polychlorobenzenes in this laboratory by McCullough,[57] the probable cause of the disproportionation is due to a buildup of amide ion. Addition of ethanol, as mentioned earlier, completely suppressed any disproportionation. Further work and analysis of the disproportionation of polychlorobenzenes will be discussed later in this thesis.

The combination of substitution and disproportionation severely limited the amount of reduction that occurred in the reactions of the polychlorobenzenes carried out under these conditions with sodium in liquid ammonia. It was thus decided to investigate the possibility of complete dechlorination by employing excess amounts of sodium in the presence of an added proton source, and these reactions will be described shortly.

The major portion of the experimental work is directed towards the reactions of chlorinated diphenylethers and related compounds with metal/ammonia solutions. These reactions are relevant to the removal of chlorines from TCDD. The structure of TCDD suggests that compounds

which could prove beneficial in reduction studies are 3- and 4-chloro-
diphenylether, 3,4-dichlorodiphenylether, 1,2-dichloro-4,5-dimethoxy-
benzene (4,5-dichloroveratrole), and dibenzo-1,4-dioxin.  The strucures
of these compounds, except for the dibenzo-1,4-dioxin, are given in
Figure 3.  The reactions of these compounds with metal/ammonia
solutions will be described in this work.  Several other compounds
which were found to be relevant to gain a greater understanding of
the reactions occurring were also studied.

Armed with the knowledge gained from the B.Sc.(Hons.) work
concerning substitution and disproportionation occurring during the
reactions with metal/ammonia solutions, the reactions were performed
using added ethanol as a proton source, although a few reactions were
studied using no added ethanol to see of there was any evidence of
the secondary processes occurring. Two substrates were also reacted
with potassium amide to see if any substitution or disproportionation
occurred.

The choice of the metal used was also investigated in a few
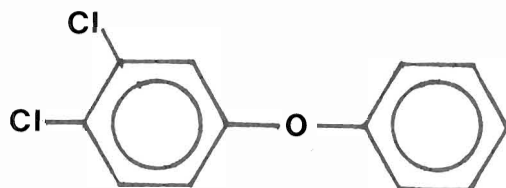reactions, and will be commented on.

Finally, the significance of metal/ammonia reduction to the
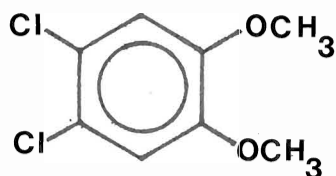degradation and detoxification of TCDD and other halogenated pollutants
will be discussed.
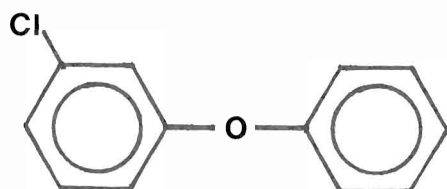
3-Chlorodiphenylether
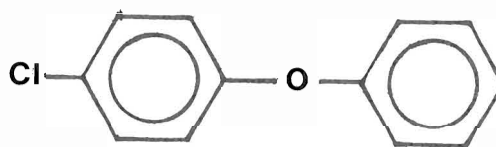


4-Chlorodiphenylether



3,4-Dichlorodiphenylether



4,5-Dichloroveratrole

Figure 3: Compounds Related to TCDD which were Reduced

## Results and Discussion

### Synthesis of Starting Materials

The most commonly used method for the preparation of diphenyl-
ethers and dibenzo-1,4-dioxins has been the Ullmann condensation. This
reaction has been known for about eighty years since Ullmann[58] prepared
diphenylether from phenol (in the form of its sodium salt) and bromo-
benzene. The reaction usually involves the coupling of phenol salts
with halobenzenes employing copper or copper salts as catalysts. It
was originally planned to use this reaction to prepare all of the
required diphenylethers as well as dibenzo-1,4-dioxin. Attempts to
prepare 4-chlorodiphenylether by Ullmann condensation led to poor
yields of the desired product. It was thought that the type of copper
used may have had an effect on the yields. Other workers have
experienced varied results in yields depending upon the type of copper
employed.[59] Fanta[59] has stated that commercial samples of copper
powder gave irreproducible results in Ullmann condensations. Other
workers have had success with cuprous salts such as cuprous chloride
or cuprous oxide as catalysts in the reactions.[60,61] There is evidence
to support the formation of an intermediate organo-copper complex with
a phenol salt in the reaction mechanism.[60] It has also been found
that the reactivity of the halobenzenes is similar to nucleophilic
aromatic substitution, that is iodides and bromides react faster than
chlorides which react much faster than fluorides.[62] The addition of

electron attracting groups in ortho or para positions of the halo-
benzenes increases the rate of reaction, which is similar to events
in a nucleophilic aromatic substitution reaction.[62]

The preparation of 4-chlorodiphenylether was tried using 4-chloro-
phenol with bromobenzene and also by using 1,4-dichlorobenzene with
phenol in the presence of copper powder, but only low yields of product
were obtained. The reactions were performed both with and without
solvents but did not give satisfactory yields of 4-chlorodiphenylether.
The grade of copper used was an electrolytic grade, which has been
found to be a satisfactory grade for Ullmann reactions.[63] A method of
activation of the copper. which is common for activating copper bronze
was employed, but this did not improve the yields. This method of
preparation of the diphenylethers was not pursued any further since
a superior method was found which gave very good yields of products
under fairly mild conditions.

It has been found by many workers that phenol salts can couple
with diaryliodonium salts to give diphenylethers in good yields.[64]
Diaryliodonium salts, of the structure (VI), have been known for many
years.



(VI)
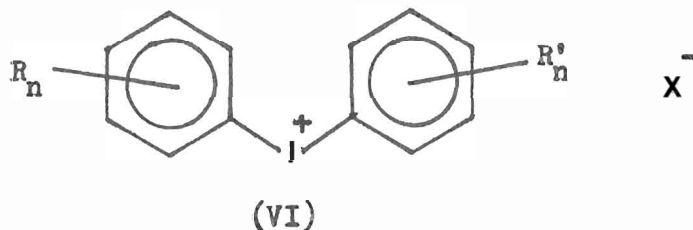
There have been a variety of procedures given for the preparation of diaryliodonium salts. The simplest and easiest method involves the reaction of an aromatic substrate with potassium iodate in sulphuric acid/acetic anhydride.[65] Other methods of preparation require the synthesis of intermediate compounds such as iodosobenzenes (VII) or iodoxybenzenes (VIII) and hence can be tedious.[65]
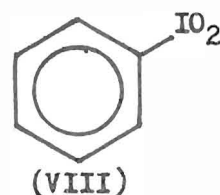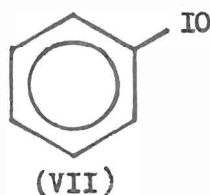


The yields of the diaryliodonium salts by the potassium iodate method are generally lower than with iodosobenzenes or iodoxybenzenes, but the greater convenience makes it a more practical method of preparation.

The utilization of diaryliodonium salts in the preparation of diphenylethers was realized in 1963 when Crowder et al[66] prepared diphenylether in a 72% yield from phenol and diphenyliodonium bromide.

Scheme 5 gives the general procedure for producing diphenylethers using diphenyliodonium chlorides. The substituents are listed to show which diphenylethers were prepared in this work.

A wide variety of substituted diphenylethers can be made simply by varying the phenol or the diaryliodonium salt. Two types of diaryl-iodonium salts were utilized in the preparation of the diphenylethers. Diphenyliodonium chloride was used to prepare diphenylethers with one

$R^1 = 3\text{-Cl, } 4\text{-Cl, } 4\text{-CH}_3 \; ; \quad x = 1,2$

$R^2 = H, \; CH_3$
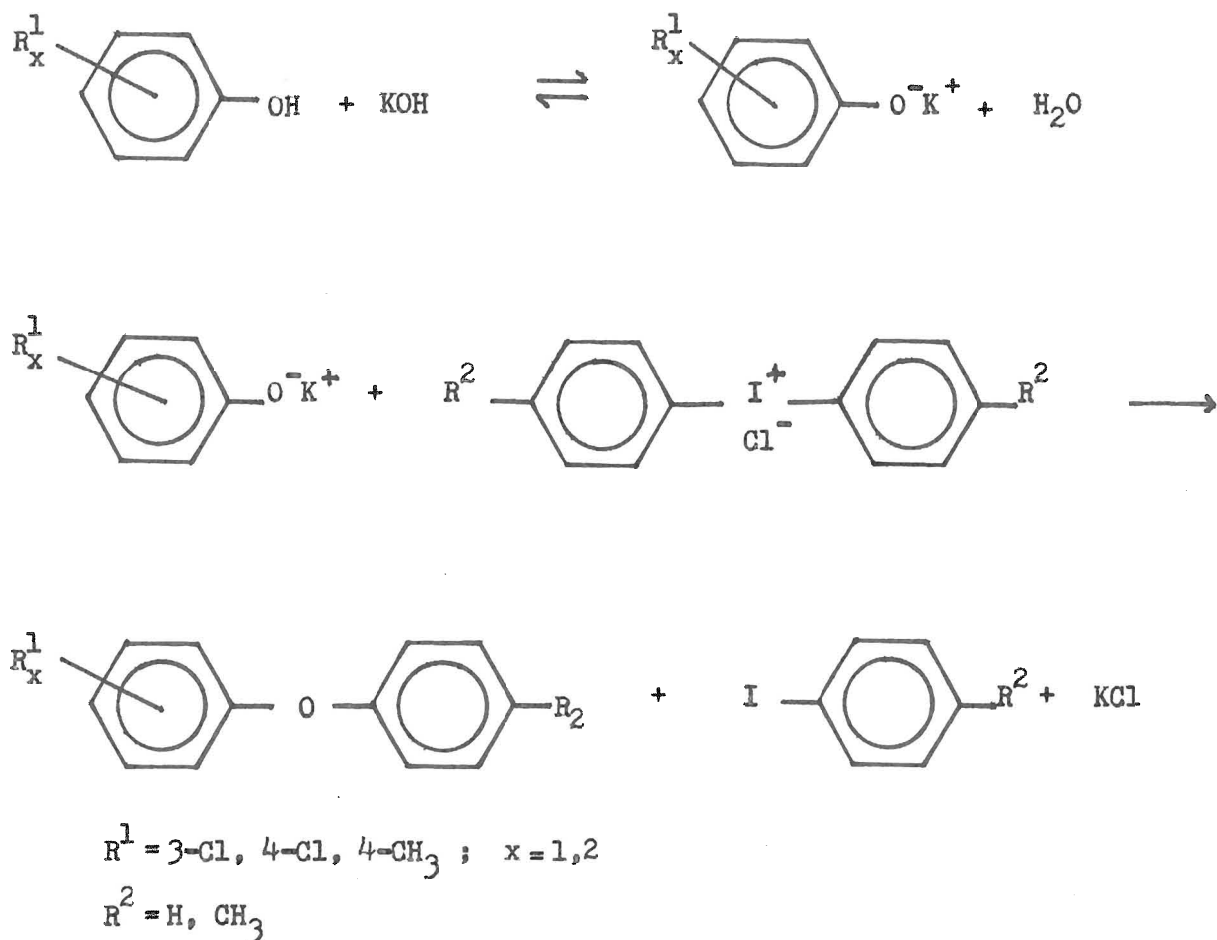
## Scheme 5

unsubstituted aromatic ring. 4,4'-Dimethyldiphenyliodonium chloride
was used to give a 4-methyl substituted diphenylether. The yields
obtained were quite good in the preparation of the diphenylethers.
Table 2 summarizes the diphenylethers that were prepared and gives the
isolated yields of the pure products. The reactions were quite clean
and were worked up by standard techniques. Iodobenzenes were produced
according to Scheme 5 and had to be removed by fractional distillation

| Phenol | Iodonium Salt[a] | Diphenylether | %Yield[b] |
|---|---|---|---|
| 4-Chloro | I | 4-Chloro | 78.2 |
| 3-Chloro | I | 3-Chloro | 79.2 |
| 3,4-Dichloro | I | 3,4-Dichloro | 69.4 |
| 4-Chloro | II | 4-Chloro-4'-Methyl | 75.6 |
| 4-Methyl | I | 4-Methyl | 53.2 |

a: I: Diphenyliodonium chloride

   II: 4,4'-Dimethyldiphenyliodonium chloride

b:  All yields are isolated yields of the pure materials.

Table 2: Preparation of Diphenylethers

and column chromatography. Chlorobenzene was obtained as a minor by-product in all cases, except in the preparation of 4-chloro-4'-methyldiphenylether. Its formation can be attributed to decomposition of the diphenyliodonium chloride to give chlorobenzene and iodobenzene. The diaryliodonium salts are known to decompose when exposed to high temperatures.[67] In the case where 4,4'-dimethyldiphenyliodonium chloride was used, 4-chlorotoluene was produced as a minor by-product, again by decomposition of the diaryliodonium chloride. The purity of all of the prepared diphenylethers was checked by tlc(hexane) and glc (20-200°C @ 20°C/min.) and indicated single components in all cases.

4,5-Dichloroveratrole was obtained from treatment of veratrole with sulphuryl chloride according to a literature preparation.[68] The compound was obtained in an 84% yield after recrystallization from ethanol. Purity was checked by m.p.,tlc (hexane) and glc (20-200°C @ 20°C/min.) which indicated that the material contained a single component.

Dibenzo-1,4-dioxin was obtained from the Ullmann condensation of 2-bromophenol. The preparation proved to be somewhat troublesome and several preparations had to be used to obtain enough material for subsequent purification followed by reaction with sodium in liquid ammonia. Substitution of the 2-bromophenol with 2-chlorophenol in the preparation gave very poor yields of the required dibenzo-1,4-dioxin. The low yields in this preparation are not too surprising since Ullmann condensations frequently give low yields of products and the preparation of dibenzo-1,4-dioxin is, in effect, two Ullmann condensations on the same starting material. The yield obtained in one preparation however, which was 55.4%, was consistent with similar literature preparations.[69]

Two types of copper powder were employed: an electrolytic grade and an electrolytic dust grade. The yields using the different copper powder grades were virtually identical; however, the electrolytic dust grade appeared to give a cleaner product ( a yellow solid as opposed to a dark brown solid ) and thus seems to be a better choice of copper powder to use. The dibenzo-1,4-dioxin did not crystallize too well ( from ethanol ) and gave brown crystalline material (m.p. 119-20°C), but further recrystallization was not attempted since the complete amount of material present was required for the subsequent reaction with sodium in liquid ammonia.

## Reductions of Polyhalogenobenzenes

The reductions of chlorobenzene, 1,2-, 1,3- and 1,4-dichlorobenzene, 1,2,3-, 1,2,4- and 1,3,5-trichlorobenzene and 1,2,3,4-, 1,2,3,5- and 1,2,4,5-tetrachlorobenzene with sodium in liquid ammonia were completed in the B.Sc.(Hons.) work. The reductions were performed both with and without added ethanol and the ratio of sodium to the substrate was kept at two to one. In addition, the reductions of pentachlorobenzene and hexachlorobenzene were done with added ethanol and using a two-fold molar ratio of sodium to polychlorobenzene. The reductions of these last two compounds without added ethanol were not studied in the B.Sc. (Hons.) work and hence were performed in the work described here. The complete reductions, using an excess of sodium and ethanol in liquid ammonia, of the tetrachlorobenzenes and of chlorobenzene and penta-

chlorobenzene were also studied. As well, two competitive reductions, using different halobenzenes, were studied, and the results of all of these reactions are given in Table 3.

The reaction of pentachlorobenzene with two moles of sodium in liquid ammonia gave 1% 1,3,5-trichlorobenzene, 17.7% of an unresolved mixture of 1,2,3,5- and/or 1,2,4,5-tetrachlorobenzene, 72.9% of unreacted pentachlorobenzene and 8.5% hexachlorobenzene. Disproportionation occurred to give the hexachlorobenzene as well as at least half of the tetrachlorobenzenes. Theoretically, disproportionation would give equal amounts of the two products, assuming no further reactions took place, however about twice as much of the tetrachloro-benzenes were produced as was the hexachlorobenzene. Two possiblilities for this discrepency are that the excess hexachlorobenzene was reduced to pentachlorobenzene or that some of the tetrachlorobenzenes were formed from reduction of the pentachlorobenzene. 1,3,5-Trichlorobenzene was probably produced through a reduction process. Disproportionation of a tetrachlorobenzene to give the 1,3,5-tetrachlorobenzene is an unlikely course since in results to be discussed in the next section, 1,2,3,5-tetrachlorobenzene disproportionation only occurred to a trace amount and 1,2,4,5-tetrachlorobenzene did not undergo disproportionation at all. No 1,2,3,4-tetrachlorobenzene was detected from the reduction of pentachlorobenzene; hence 1,3,5-trichlorobenzene must have been formed from a reduction process. The mechanism of disproportionation will be discussed in the next section. Clearly, the omission of ethanol in the reaction mixture is undesirable as it severely hinders the amount of

| Halobenzene Substrate | Reagent[a] | Time(min.) | Products(%)[b] |
|---|---|---|---|
| PhCl | Na/C$_2$H$_5$OH (2) | 10 | benzene(100) |
| PhCl + PhF | " | - | benzene,PhCl,PhF |
| PhCl + PhBr | " | - | benzene,PhCl(45.5),PhBr(54.5) |
| 1,2,3,4-Cl$_4$ | Na/C$_2$H$_5$OH (8) | 5 | benzene,1,4-cyclohexadiene |
| 1,2,3,5-Cl$_4$ | " | 5 | benzene,1,4-cyclohexadiene, 1,2,3,5-Cl$_4$(tr) |
| 1,2,4,5-Cl$_4$ | " | 5 | benzene,1,4-cyclohexadiene, 1,2,4,5-Cl$_4$(tr) |
| Cl$_5$ | Na (2) | 240 | 1,3,5-Cl$_3$(1),1,2,3,5/1,2,4,5-Cl$_4$(17.7),Cl$_5$(72.9),Cl$_6$(8.5) |
| Cl$_5$ | Na/C$_2$H$_5$OH (10) | 30 | 1,4-cyclohexadiene(100) |
| Cl$_6$ | Na (2) | 240 | Cl$_5$(1.2),Ph$_2$NH(4.1),Cl$_6$(80.7), unknown(14.1) |

a: Quantities in brackets are the molar ratios of sodium to substrate

b: Product yields, which were calibrated, were determined by glc in the cases where mixtures were produced and are given in relative amounts; tr: trace amount obtained

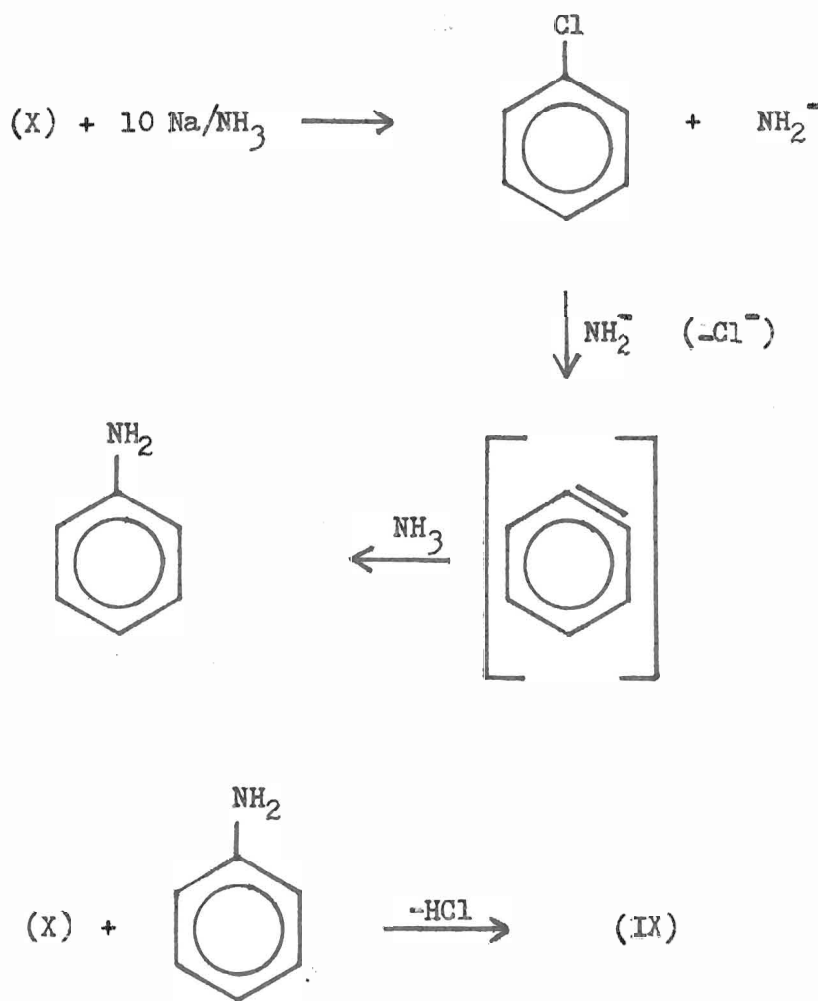Table 3: Reductions of Polyhalogenobenzenes in Liquid Ammonia

reduction that takes place and leads to large amounts of disproportionation products.

The reaction of hexachlorobenzene with two moles of sodium in liquid ammonia gave 1.2% pentachlorobenzene, 4.1% diphenylamine, 80.7% unreacted hexachlorobenzene and 19.3% of a mixture of unidentified compounds having molecular ions (from the gc/ms) with five chlorine atoms. The formation of pentachlorobenzene is a reduction process and involves the reduction of one carbon-chlorine bond of hexachlorobenzene. The formation of diphenylamine however, implies a mixture of reduction and substitution was occurring. A possible scheme to account for diphenylamine is reduction of hexachlorobenzene to give chlorobenzene followed by a benzyne reaction with amide ion, which would be formed as the reduction proceeds, to give aniline. Aniline could then add, via a benzyne intermediate, to chlorobenzene to give diphenylamine or conversely, it can add to hexachlorobenzene to give pentachlorodiphenylamine which could then be reduced to diphenylamine. Support for this last mechanism lies in the tentative identification of pentachlorodiphenylamine (IX) in the unidentified mixture of compounds from the hexachlorobenzene reaction. The gc/ms gave a component having $\underline{m/e}$ 343,341,339,77,51 which would be consistent with (IX).
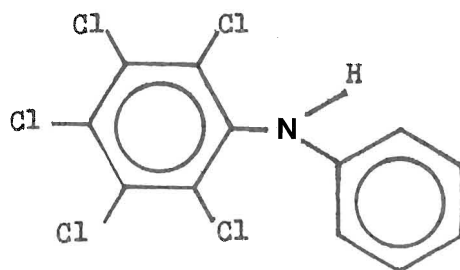


(IX)

A possible scheme for the formation of (IX) from hexachlorobenzene
(X) is given in Scheme 6.

$$(X) + 10\ Na/NH_3 \longrightarrow \quad \text{(chlorobenzene with Cl)} \quad + \quad NH_2^{\ -}$$

$$\downarrow NH_2^{\ -} \quad (-Cl^{\ -})$$

$$\text{(aniline, NH}_2\text{)} \quad \xleftarrow{\ NH_3\ } \quad \text{[benzyne intermediate]}$$

$$(X) + \quad \text{(aniline, NH}_2\text{)} \quad \xrightarrow{\ -HCl\ } \quad (IX)$$

### Scheme 6

It is clear from these last two reactions and from the B.Sc.(Hons.)
work that addition of a proton source such as ethanol would eliminate
many of the side reactions which occurred. In addition, excess sodium

should completely remove the chlorines form the polychlorobenzenes, an objective consistent with the aims of this work. It is expected that benzene should be produced which is what has been found in the reduction of the monchalobenzenes.[40] One problem that was encountered during the B.Sc.(Hons.) work was that volatile products such as benzene were lost during the work-up. In the work-up procedure, the ammonia was allowed to evaporate off prior to addition of water and ether for extraction. This procedure was altered during the course of the work here by adding water to the reaction mixture still containing the liquid ammonia. A large excess of water (about three times the volume of ammonia) was required to give a solution which could be safely extracted with ether.

The reduction of chlorobenzene with sodium and ethanol in liquid ammonia gave benzene as the only detectable product (gc/ms), which is consistent with the results of Hudson.[40] The recovery of benzene was only 8.7% however, due to product loss during the work-up. No chlorobenzene was detected by gc/ms and the reaction was complete (by observance of the discharge of the blue colour) in ten minutes.

Two competitive runs were performed to observe the effect of different halogens in the aromatic ring. Equimolar mixtures of chlorobenzene/fluorobenzene and chlorobenzene/bromobenzene were each reduced with sodium and ethanol in liquid ammonia. The amount of sodium employed was equal to the total number of moles of the combined starting materials, that is it was equal to half of the amount required for the reduction of both substrates. The reaction involving fluorobenzene was more

vigorous than the reaction involving bromobenzene, which may suggest
that electron addition is an important step in the overall rate of
the reduction. The competitive reduction of chlorobenzene/bromobenzene
gave a product distribution of benzene, 45.5% chlorobenzene and 54.5%
bromobenzene, suggesting that chlorobenzene was slightly more easily
reduced than bromobenzene. The competitive reduction of chlorobenzene/
fluorobenzene gave an unresolved mixture (gc/ms) of benzene and fluoro-
benzene as well as chlorobenzene. It is difficult to assign definite
conclusions from the product distributions from the competitive runs
due to problems in volatility of products. It does seem likely however,
that the reduction by sodium and ethanol in liquid ammonia can be
applied with comparative ease to any halogenobenzene. This is in
contrast to other methods such as reduction by lithium aluminum hydride
where chlorides are difficult to reduce.[70] In this laboratory, penta-
chlorobenzene and hexachlorobenzene reacted with difficulty with lithium
aluminum hydride in refluxing tetrahydrofuran. Pentachlorobenzene gave
a tetrachlorobenzene(s) plus major amounts of unreacted starting material,
and hexachlorobenzene gave pentachlorobenzene, a tetrachlorobenzene(s)
along with major amounts of unreacted starting material.[57]

The mechanism of the sodium/liquid ammonia reduction of organic
halides and aromatic compounds has been investigated by a number of
workers. They have suggested that protonation of the intermediate
radical-anion by the added proton source is the rate determining step.[40,71]
The following mechanism, Scheme 7, has been proposed by Hudson[40] for the
reduction of halobenzenes by sodium and ethanol in liquid ammonia.
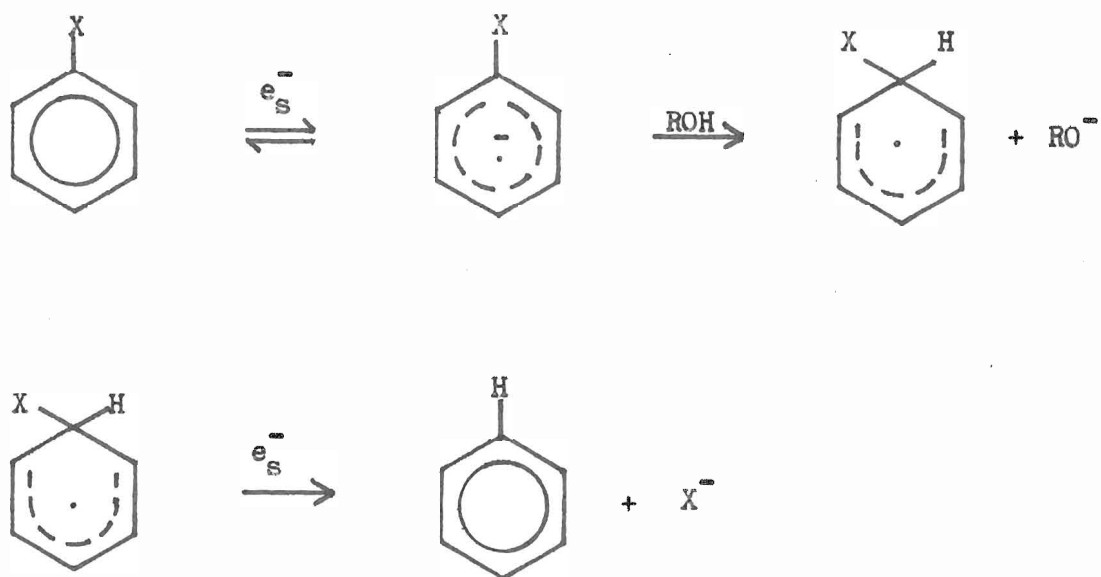
Scheme 7

The rate determining step in the mechanism is the addition of ethanol to give the radical intermediate. The addition of electrons would be a rapid process due to the high reactivity of the solvated electrons.

The result of the chlorobenzene reduction indicated that complete reduction of aromatic chlorides was possible. The reductions of the tetrachlorobenzenes and of pentachlorobenzene using an eight-fold and a ten-fold molar ratio of sodium and ethanol to the substrate respectively were carried out.

The tetrachlorobenzenes gave mixtures of benzene and 1,4-cyclohexa-diene in all cases and only traces of unreacted starting materials in the reductions of 1,2,3,5- and 1,2,4,5-tetrachlorobenzene. The reaction

times were very fast in all cases; the approximate time for discharge
of the blue colour being about five minutes. Pentachlorobenzene gave,
after a thirty minute reaction, a 100% conversion to 1,4-cyclohexadiene.
Thus, the polychlorobenzenes were readily reduced to benzene and 1,4-cyclo-
hexadiene, after short reaction times by the action of sodium and
ethanol in liquid ammonia. No attempt was made to see if lithium metal
had the same effect on the polychlorobenzenes. The advantage of sodium
metal over lithium metal is that sodium is more economical and is easier
to work with, being easier to cut than lithium. The major disadvantage
with sodium is that the higher basicity of its salts, particularily the
amide salt, increases the chances of secondary processes such as reactions
via aryne intermediates. This does not seem to present a problem
however, when an excess of sodium and ethanol is employed. The
resulting reaction is very clean and is easy to monitor by observance
of the disappearance of the blue colour due to excess solvated electrons.
Other proton sources such as t-butanol could also be used, but the cost
and ease of handling of ethanol makes it particularly attractive from
a practical standpoint. In summary therefore, the reductions of poly-
halogenated benzenes using an excess of sodium and ethanol in liquid
ammonia gave virtually 100% conversion to benzene and/or 1,4-cyclo-
hexadiene after short reaction times. There was no evidence of any
secondary processes having occurred.

## Disproportionation of Polychlorobenzenes

As was mentioned during the introduction, disproportionation occurred during the reductions of 1,2,3,4-tetrachlorobenzene and pentachlorobenzene with sodium in liquid ammonia. These reactions were performed in the B.Sc.(Hons.) work. The cause of the disproportionation was given as being due to a build-up of amide ion as the reduction proceeded. This was tested by studying the reactions of the tetrachlorobenzenes and of pentachlorobenzene with potassium amide and with potassium anilide. This work was primarily conducted by McCullough in this laboratory.[57] There were two areas of work however which required either redoing or further analysis. First, the glc traces were not calibrated and the separation and resolution of the product mixtures were poor due to an inefficient column. Second, during the reactions of 1,2,3,4- and 1,2,3,5-tetrachlorobenzene, there was present an impurity of pentachlorobenzene in the two starting materials. This could have acted as a co-catalyst to isomerize the tetrachlorobenzenes which could then react further. Bunnett and Scorrano[72] have noted the effect of a co-catalyst in the isomerization of 1,3,5-tribromobenzene to 1,2,4-tribromobenzene using 1,2,3,5-tetrabromobenzene as a co-catalyst. The mechanism of isomerization will be discussed shortly. The appearance of pentachlorobenzene may have caused additional reactions; hence the tetrachlorobenzenes were purified until glc indicated only one component was present.

The results of the disproportionation studies on the tetrachloro-

benzenes and pentachlorobenzene are summarized in Table 4. The work from three sources are given: McCullough's disproportionation studies using potassium amide and potassium anilide, the disproportionation which occurred during the B.Sc.(Hons.) work and work that was conducted for this thesis.

From the table, no disproportionation occurred with 1,2,4,5-tetrachlorobenzene. Purified 1,2,3,5-tetrachlorobenzene gave no disproportionation with potassium amide, which is in contrast to the reaction of the compound with sodium in liquid ammonia where 1,3,5-trichlorobenzene and pentachlorobenzene were produced from disproportionation. Purified 1,2,3,4-tetrachlorobenzene gave 1,2,4-trichlorobenzene and pentachlorobenzene as disproportionation products. As well, traces of 1,2,3,5- and/or 1,2,4,5-tetrachlorobenzene were produced. The amount of disproportionation of 1,2,3,4-tetrachlorobenzene increased during the reaction with sodium in liquid ammonia, although there was no evidence of isomerization of 1,2,3,4-tetrachlorobenzene. Pentachlorobenzene disproportionated to 1,2,3,5- and possibly 1,2,4,5-tetrachlorobenzene and hexachlorobenzene during reaction with potassium amide or with sodium in liquid ammonia.

A problem occurred in identification of product mixtures in that the tetrachlorobenzene isomers, 1,2,3,5- and 1,2,4,5-tetrachlorobenzene, were not separated by glc. A variety of glc columns and conditions were employed in attempts to separate a mixture of the two chlorobenzene isomers but the results made positive identification of a particular isomer uncertain. A possible method of differentiation was by ^{1}H nmr

| Chlorobenzene Isomer | Reagent | Source[a] | Products[b](%) |
|---|---|---|---|
| $1,2,3,4$-$Cl_4$ | $KNH_2$ | $A^c$ | $1,2,4$-$Cl_3(1)$,S.M.$(98)$,$Cl_5(1)$ |
| | PhNHK | A | S.M.$(88.9)$,PhNHPhCl$_3$/PhNHPhCl$_4(0.9)$, PhNH$_2(10.2)$ |
| | $KNH_2$ | B | $1,2,4$-$Cl_3(3.7)$,S.M.$(92.5)$,$1,2,3,5$-/$1,2,4,5$-$Cl_4(tr)$,$Cl_5(3.8)$ |
| | Na/NH$_3$ | C | $1,2,4$-$Cl_3(18)$,S.M.$(36)$,$Cl_5(36)$, $Cl_2PhNH_2(10)$ |
| $1,2,3,5$-$Cl_4$ | $KNH_2$ | $A^c$ | $1,3,5$-$Cl_3(7)$,S.M.$(81)$,$Cl_5(12)$ |
| | PhNHK | $A^c$ | $1,3,5$-$Cl_3(1)$,S.M.$(79)$,$Cl_5(1)$, PhNHPhCl$_3(1)$,PhNH$_2(19)$ |
| | $KNH_2$ | B | S.M.$(100)$ |
| | Na/NH$_3$ | C | $1,3,5$-$Cl_3(18)$,S.M.$(66)$,$Cl_5(16)$ |
| $1,2,4,5$-$Cl_4$ | $KNH_2$ | A | S.M.$(100)$ |
| | PhNHK | A | $1,2,4$-$Cl_3(tr)$,S.M.$(99)$,PhNHPhCl$(tr)$, PhN=NPh$(tr)$ |
| $Cl_5$ | $KNH_2$ | A | $1,2,3,5$-/$1,2,4,5$-$Cl_4(9.5)$,S.M.$(80)$, $Cl_6(10.5)$ |
| | PhNHK | A | S.M.$(99)$,PhNHPhCl$_4(tr)$ |
| | Na/NH$_3$ | C | $1,2,3,5$-/$1,2,4,5$-$Cl_4(22)$,S.M.$(55)$, $Cl_6(23)$,Ph$_2$NH$(1)$,$Cl_4$-PhNH$_2(tr)$ |

a: A- C.A.M. McCullough, Summer Research Student; B- This work; C- S.R. Cater, B.Sc.(Hons.) Thesis

b: % yields determined by glc; tr- trace obtained; S.M.- starting material

c: contained pentachlorobenzene impurity

Table 4: Disproportionation of Polychlorobenzenes

spectroscopy since 1,2,3,5-tetrachlorobenzene gave a singlet at $\delta$ 7.37 and 1,2,4,5-tetrachlorobenzene gave a singlet at $\delta$ 7.58. The product mixtures from the disproportionation reactions contained the unreacted starting materials as the major components. The crude product mixtures from the three disproportionation reactions, namely those of 1,2,3,4- and 1,2,3,5-tetrachlorobenzene and pentachlorobenzene, with potassium amide were fractionally crystallized to remove the unreacted starting material. The mother liquors, which still contained the unreacted starting material as the major components were then subjected to analysis by $^1$H nmr, glc and gc/ms techniques.

The $^1$H nmr spectrum of the mother liquor from the disproportionation of pentachlorobenzene included a signal at $\delta$ 7.38, possibly due to 1,2,3,5-tetrachlorobenzene. Glc and gc/ms confirmed the presence of one or both of 1,2,3,5- and 1,2,4,5-tetrachlorobenzene. It was difficult to ascertain by $^1$H nmr spectroscopy whether 1,2,4,5-tetrachlorobenzene was present as the signal for pentachlorobenzene occurred at $\delta$ 7.5 and was very intense, which may have masked any signal due to 1,2,4,5-tetrachlorobenzene.

The analysis of the other mother liquors did not reveal any further information on the identification of the tetrachlorobenzene isomers. Glc and gc/ms of the mother liquors did however give slightly stronger signals for the disproportionation products making for more accurate retention time determinations for comparison with standards. The nonseparation of 1,2,3,5- and 1,2,4,5-tetrachlorobenzene by glc has been observed by other workers.[56]

The mechanisms of disproportionation and isomerization of poly-halogenobenzenes have been extensively studied by Bunnett and co-workers.[56,72,73] Their mechanism of disproportionation is base catalyzed and is represented in Scheme 8 for the disproportionation of penta-chlorobenzene.



(XI)        (XII)        ---(7)

(XII) + (XI) ⇌ Cl$_6$        (XIII)        ---(8)

(XIII) + BH ⇌        + B⁻        ---(9)
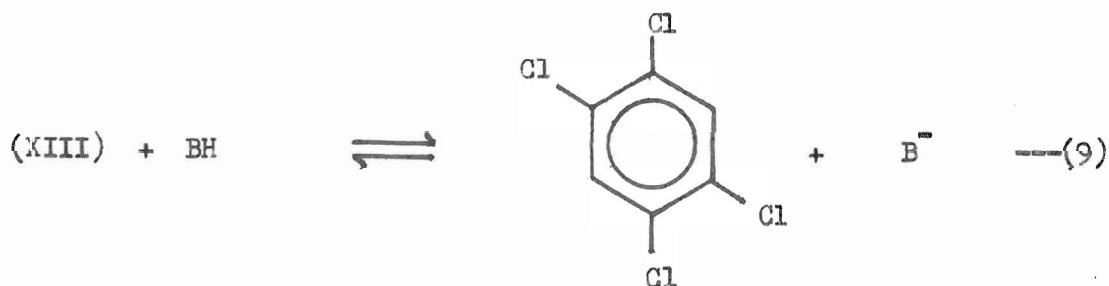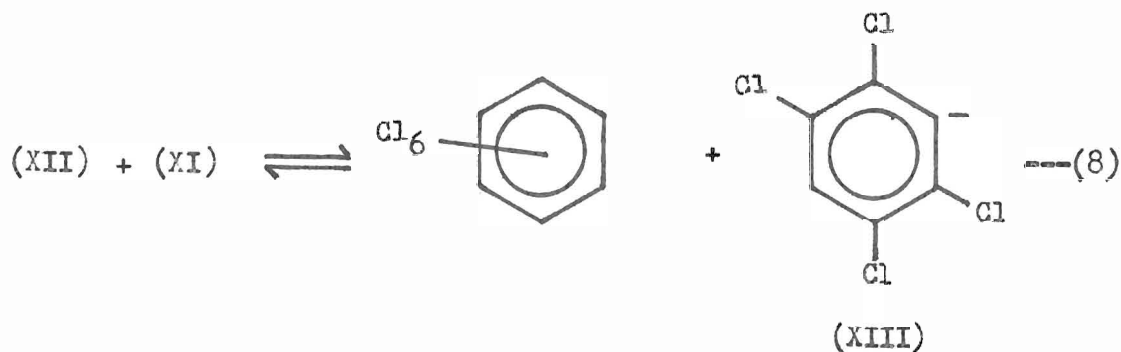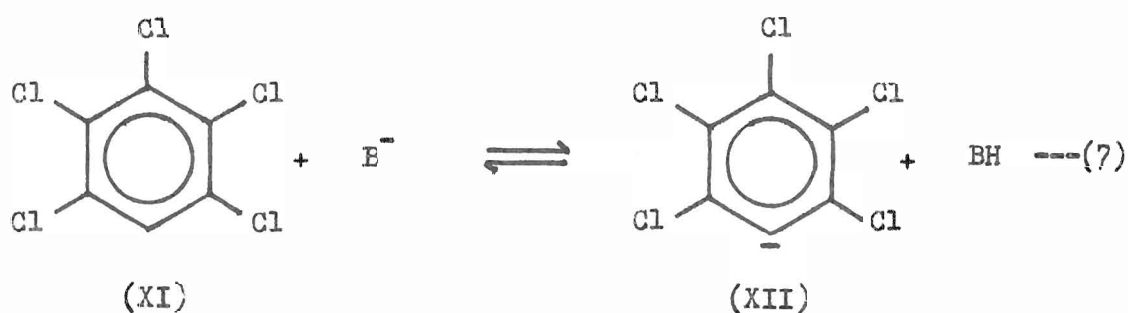
Scheme 8

In equation (7) a base, represented by B⁻ abstracts a proton from pentachlorobenzene to give the anion (XII). This anion then attacks a second molecule of pentachlorobenzene to remove a chlorine giving hexachlorobenzene and the anion (XIII) which is protonated in equation (9) to give 1,2,4,5-tetrachlorobenzene. Abstraction of the 2-chlorine from pentachlorobenzene in equation (8) would ultimately lead to 1,2,3,5-tetrachlorobenzene.

The nature of the base has been extensively studied. In this work the base employed was potassium amide, but potassium t-butoxide and potassium anilide have been employed by other workers.[56,57,72,73]

The key step in the mechanism involves a positive halogen transfer, represented in equation (8). Other mechanisms which could be envisioned, such as an aryne mechanism or a radical mechanism have been ruled out by Bunnett and co-workers.[72,73] The reactivity of the halogens towards disproportionation has been found to be iodine > bromine > chlorine > fluorine, which is supportive of a positive halogen transfer.[72,73]

The work of McCullough[57] on the disproportionation of the tetrachlorobenzenes and of pentachlorobenzene showed that potassium amide was more effective than potassium anilide in promoting disproportionation. This can be explained by the fact that potassium amide is a stronger base than is potassium anilide and hence would be more effective in removing a proton in equation (7). This is in contrast to the results of Bunnett and co-workers[72,73] who found that disproportionation and isomerization of 1,2,4-tribromobenzene occurred more readily with potassium anilide than with potassium amide. They gave a possible

explanation, in the case of the polybromobenzenes, as being that aryne formation could be faster than disproportionation with potassium amide as the base. This would probably not be such as large an effect for the polychlorobenzenes since the reactivity in aryne reactions is bromides > iodides > chlorides > fluorides.[74] Thus the competing aryne substitution should not be as great with the chlorobenzenes. This means that the potassium amide and the chlorobenzenes would not be consumed so readily via substitution reactions and would be available for promoting disproportionation. Another explanation that could account for less disproportionation using potassium anilide can be found in the analysis of some by-products that were obtained in the reactions by McCullough[57] using potassium anilide. These included some trichloro- and tetrachlorodiphenylamines which were probably formed by substitution reactions of aniline or potassium anilide with the polychlorobenzene. This would result in less of the base present to promote disproportionation.

In general, there was more disproportionation during the reductions by sodium in liquid ammonia than by the action of potassium amide. This may have been due to a concentration effect since the concentration of potassium amide was held to one-half of the concentration of the poly-chlorobenzene whereas the concentration of amide ion during the reduction by sodium in liquid ammonia would increase as the reduction proceeds. No attempt was made in this work or by McCullough[57] to study the effect of base concentration on the amount of disproportionation that occurred. The results of Bunnett and co-workers[72,73] generally show an increase

in disproportionation upon increasing the concentration of amide ion or other base; hence it may be possible that the concentration of amide ion rose to a higher level during the reduction of the polychloro-benzenes than was present in the disproportionation studies using potassium amide.

There was only one instance of any isomerization of the polychloro-benzenes being detected. This was for the reaction of 1,2,3,4-tetra-chlorobenzene with potassium amide and gave trace amounts of 1,2,3,5-tetrachlorobenzene and possibly 1,2,4,5-tetrachlorobenzene as well. This is in contrast to the results of Bunnett and co-workers[72,73] who observed extensive isomerization of the tribromobenzenes. They also observed the isomerization of 1,2,3,5- and 1,2,4,5-tetrachlorobenzene during the reaction of these substrates with potassium t-butoxide in hexamethylphosphoric triamide (HMPA).[56]

The proposed mechanism of the isomerization of 1,2,3,4-tetra-chlorobenzene , analogous to the mechanism proposed by Bunnett and co-workers,[72,73] requires the involvement of pentachlorobenzene, which would be formed from disproportionation of 1,2,3,4-tetrachlorobenzene. The mechanism is given in Scheme 9.

The mechanism has similarities to the disproportionation mechanism given in Scheme 8. The first step is the generation of the anion (XIV) from attack of the base B⁻ with 1,2,3,4-tetrachlorobenzene. In equation (11), the anion (XIV) then abstracts a chlorine from pentachlorobenzene which regenerates the pentachlorobenzene and gives the anion of 1,2,3,5-or 1,2,4,5-tetrachlorobenzene, although only the anion for 1,2,3,5-

$$(XIV) \quad (XV) \quad (XVI)$$
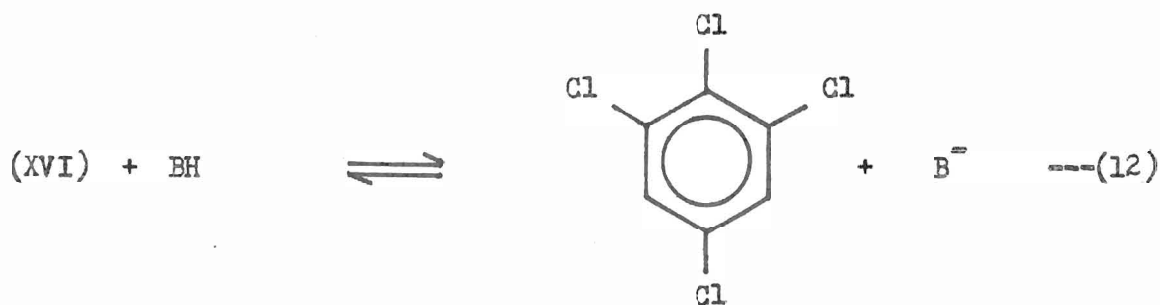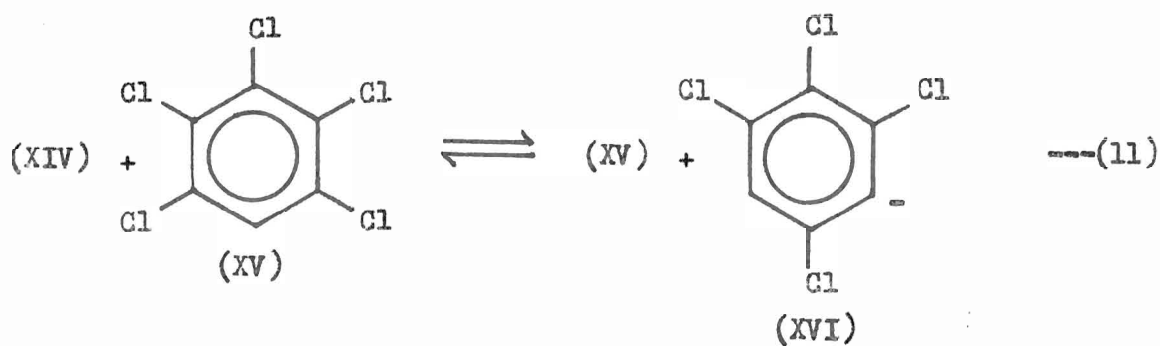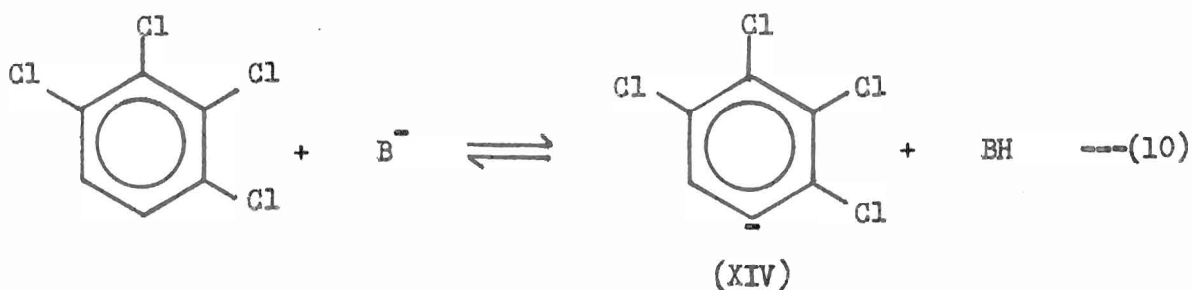
## Scheme 9

tetrachlorobenzene (XVI) is shown in Scheme 9. The final step involves

protonation of the anion (XVI) to give 1,2,3,5- or 1,2,4,5-tetrachloro-

benzene. Pentachlorobenzene acts as a co-catalyst since it is regenerated

in equation (11). The fact that only a trace amount of isomerization

occurred attests to the fact that chlorine is not as labile as bromine towards base-catalyzed isomerization. This is supportive of the positive halogen transfer which is the key step of the mechanism of both isomerization and disproportionation. That Bunnett[56] observed a fair amount of isomerization of 1,2,3,5- and 1,2,4,5-tetrachlorobenzene with potassium t-butoxide in HMPA suggests that the type of base and possibly solvent effects are important in the amount of disproportionation that occurs.

Disproportionation is an unwanted side reaction that occurred during some attempted dehalogenations of polyhalogenated aromatic compounds. This leads to products which have more halogens than the original material. Disproportionation was completely suppressed by the addition of ethanol, which inhibited the formation of amide ion during the reduction process. Thus, disproportionation does not become significant during the reduction of polyhalogenated aromatic compounds with sodium and ethanol in liquid ammonia.

## Reactions of Chlorinated Diphenylethers

The major portion of research in this work was directed towards the reactions of chlorinated diphenylethers and related compounds with sodium or lithium in liquid ammonia. The types of starting materials that were employed were those which had similar chemical structures to the chlorinated dibenzo-1,4-dioxins. These were 3- and 4-chlorodiphenylether, 3,4-dichlorodiphenylether, 4-chloro-4'-methyldiphenylether,

4,5-dichloroveratrole and dibenzo-1,4-dioxin. The reactions of diphenylether, 4-methyldiphenylether, veratrole, 4-chlorophenol, sodium and potassium 4-chlorophenate, 4-methylphenol and 4-chloro-3,5-dimethylphenol were also investigated as either control experiments or to help to determine the course of the reactions of the chlorinated substrates.

A large number of reactions were performed using 4-chlorodiphenyl-ether. The reactions are summarized in Table 5. Five basic reactions were performed on 4-chlorodiphenylether. These were reaction with sodium in liquid ammonia, reaction with sodium and ethanol in liquid ammonia, reaction with excess sodium and ethanol in liquid ammonia, reaction with lithium in liquid ammonia and reaction with potassium amide in liquid ammonia. Seven reactions in total are given in Table 5, but the reactions with sodium and with sodium and ethanol were each performed twice, using different work-ups in each case.

The reaction with a two-fold molar ratio of sodium in liquid ammonia gave a mixture containing phenol, diphenylether, a small amount of an aminodiphenylether(s), plus a trace amount of unreacted 4-chlorodiphenylether. Phenol would probably be formed from cleavage of diphenylether and thus benzene should be an expected product as well. This was confirmed when the reaction was repeated except that water was cautiously added to the reaction mixture. Benzene was detected before final concentration of the ethereal extract of reaction products. The alternative formation of phenol, involving cleavage of 4-chlorodiphenylether will be discussed later.

| Run[a] | Reagent[b] | Time(min.) | S.M.[c] | Products[d](%) |
|--------|-----------|-----------|---------|----------------|
| 1 | Na (2) | 60 | trace | phenol,DPE,$NH_2$DPE |
| 2 | Na (2) | 60 | trace | benzene,phenol,DPE,$NH_2$DPE |
| 3 | Li (2) | - | trace | " |
| 4 | Na/EtOH (2) | - | trace | benzene,phenol(64),DPE(36) |
| 5 | Na/EtOH (2) | - | 0 | benzene,phenol(65),DPE(35) |
| 6 | Na/EtOH (4) | 10 | 0 | benzene,phenol(97.8) |
| 7 | $KNH_2$ | 240 | 100 | - |

a: In run #1 the ammonia was evaporated before work-up

In run #4 an aliquot of the ether extract was washed with 5% NaOH to isolate phenol.

In run #5 the entire ether extract was washed with 5% NaOH

b: The quantities in brackets are ratio of substrate:metal

c: Refers to the recovered 4-chlorodiphenylether

d: Yields, determined by glc, are relative except for run #6 where the isolated yield is given.

DPE: diphenylether; $NH_2$DPE: an aminodiphenylether(s)

Table 5: Reactions of 4-Chlorodiphenylether in Liquid Ammonia

The formation of diphenylether was due to reduction of the carbon-chlorine bond of 4-chlorodiphenylether. The aminodiphenylether was probably formed by an aryne reaction caused by a build up of amide ion as the reduction proceeded. Reaction via an aryne intermediate should have given a mixture of 3- and 4-aminodiphenylether, analogous to other aryne reactions,[74] however this was not investigated any further.

The reaction with lithium gave virtually an identical product mixture as the reaction with sodium. The fact that there was no benefit in using lithium over sodium increases the desirability of using sodium since sodium metal is more economical and easier to use than lithium metal.

The reaction using sodium with added ethanol in a two-fold molar ratio relative to 4-chlorodiphenylether gave a mixture of benzene, 65% phenol and 35% diphenylether. Addition of ethanol completely suppressed the formation of the aminodiphenylether(s). No starting material was detected by gc/ms.

This last result suggested that the removal of chlorine from 4-chlorodiphenylether occurred very easily with sodium and ethanol in liquid ammonia. The reaction time was negligible- the reaction was quenched with ammonium chloride as soon as the last piece of sodium metal had dissolved. The total reaction time, including the addition time of the sodium, was approximately fifteen minutes.

The reaction with a four-fold molar ratio of sodium and ethanol in liquid ammonia should theoretically remove all of the chlorine to give diphenylether (consuming two moles of sodium), followed by cleavage of diphenylether to give benzene and phenol. Any further sodium present

should reduce benzene to 1,4-cyclohexadiene. Run 6 from Table 5 sum-
marizes the results of this reaction. The reaction time was ten
minutes, which was the time required for discharge of the blue colour.
The only products detected were benzene and phenol with no detectable
amounts of 4-chlorodiphenylether present. The recovery of phenol was
97.8% of the theoretical amount obtainable. Due to volatility problems,
the amount of benzene obtained was not determined, but was expected to
be well short of the theoretical recovery. This a general phenomenon
that has been noted by other workers.[44]

The reaction of 4-chlorodiphenylether with potassium amide was
carried out to determine if any substitution or, less likely, any
disproportionation would occur. The reaction using an equimolar amount
of potassium amide gave only unreacted starting material. The recovery
was about 90% of the theoretical amount. The material obtained had a
dark brown colour which suggested that there may have been very small
amounts of some additional material present, but $^1$H nmr spectroscopy
and gc/ms only detected the 4-chlorodiphenylether.

Only two reactions of 3-chlorodiphenylether were performed. These
reactions, as well as others to be described shortly, are given in
Table 6.

The reaction of 3-chlorodiphenylether with excess sodium and
ethanol, analogous to run 6 in Table 5, gave a mixture of benzene,
90% phenol and 10% of an unresolved mixture of diphenylether, a
dihydrodiphenylether and a tetrahydrodiphenylether. Based on the
mass spectrum of the unresolved mixture and on the known reduction of

| Run[a] | Reagent[b] | Time(min.) | %S.M.[c] | Products[d](%) |
|--------|-----------|-----------|----------|----------------|
| 8 | Na/EtOH (4) | 10 | 0 | benzene,phenol(90),DPE + 2HDPE + 4HDPE(10) |
| 9 | Na/EtOH (1) | 0 | 46.5 | benzene,phenol(22.8),DPE(30.7) |
| 10 | Na (2) | - | 41.4 | benzene,phenol(19.6),DPE(38.9) |
| 11 | Na/EtOH (2) | - | 40.4 | phenol(20.4),DPE(38.8) |
| 12 | Na/EtOH (6) | 15 | 0 | benzene,phenol(100) |
| 13 | Li/EtOH (6) | 15 | 0 | benzene,phenol(57.8),DPE + 4HDPE(42.2) |
| 14 | KNH$_2$ | 240 | 100 | - |
| 15 | Na/EtOH (2) | - | 0 | benzene,toluene,phenol(8.2), 4-Mephenol(26.9),4MeDPE(64.9) |

a: Runs 8,9- 3-Chlorodiphenylether

Runs 10-14- 3,4-Dichlorodiphenylether

Run 15- 4-Chloro-4'-Methyldiphenylether

b: Quantities in brackets is ratio of metal to substrate

c: Refers to recovered starting material

d: Yields calculated by glc and are relative

DPE- Diphenylether; 2HDPE- Dihydrodiphenylether; 4HDPE- Tetrahydro-diphenylether; 4-Mephenol- 4-Methylphenol; 4MeDPE- 4-Methyldiphenylether

Table 6: Reactions of 3-Chlorodiphenylether, 3,4-Dichlorodiphenylether and 4-Chloro-4'-Methyldiphenylether in Liquid Ammonia

anisole to give 2,5-dihydroanisole, the structures of the dihydro-
and the tetrahydrodiphenylethers should be expected to be (XVII) and
(XVIII) respectively.



(XVII)                                    (XVIII)
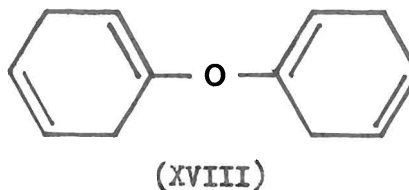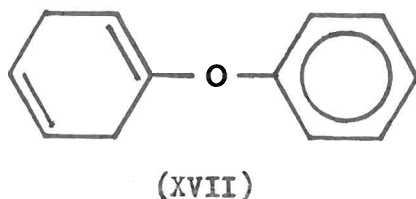
The structure (XVIII) for the tetrahydrodiphenylether, as opposed
to (XIX), is confirmed on two grounds.



(XIX)
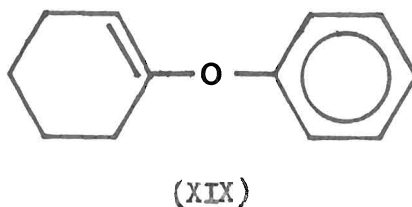
First, (XIX) would be expected to give a high intensity peak in
the mass spectrum at m/e 77 due to the aromatic ring. What was observed
was an intense peak at m/e 79. Second, the formation of (XIX) would
require conjugation of the double bonds in (XVII), followed by reduction.
This is highly unlikely since amide ion would probably be required for
the conjugation and ethanol was present which would inhibit amide ion
formation. Complete assignment of the mass spectrum for the dihydro-
and tetrahydrodiphenylethers was not possible since the mixture,

which included diphenylether, was not resolved by gc/ms.

A possible method of further identification of the dihydro-
and tetrahydrodiphenylethers lies in the acid catalyzed hydrolysis of
the compounds. The structures (XVII) and (XVIII) contain enol ethers
which can be hydrolyzed under acidic conditions. This point will be
considered later in this discussion.

The reduction of diphenylether to give the dihydro- and the
tetrahydrodiphenylether derivatives is somewhat surprising since all
of the reported reactions of diphenylether with solutions of alkali
metals in liquid ammonia have given just benzene and phenol.[33,44]
It may be possible that the 3-chlorine has an activating effect on
reduction of the diphenylether ring; however no mechanism can be
postulated at this time. Further discussion of this will be considered
later.

The reaction of 3-chlorodiphenylether with an equimolar amount
of sodium and ethanol in liquid ammonia was attempted to see if any
possible cleavage products occurred, besides benzene and phenol which
are produced after reduction of the carbon-chlorine bond. The reaction
was quenched with ammonium chloride immediately after addition of the
final piece of sodium metal. The reaction gave a mixture of benzene,
22.8% phenol, 30.7% diphenylether and 46.5% unreacted 3-chlorodiphenyl-
ether. Possible cleavage products of 3-chlorodiphenylether, such as
3-chlorophenol or chlorobenzene were not detected by gc/ms. It is
possible that these products are reduced to phenol and benzene
respectively and hence are not detected. There is strong evidence at

this time to rule this out; diphenylether was a major product especially when only an equimolar amount of 3-chlorodiphenylether and sodium were used. No products resulting from cleavage of the original chlorinated diphenylethers were detected in any of the reaction mixtures so far. A further experiment was studied to help determine the course of the reactions and will be discussed shortly.

3,4-Dichlorodiphenylether was readily reduced using sodium or lithium in liquid ammonia. The reactions are given in Table 6.

The reaction using a two-fold molar amount of sodium in liquid ammonia gave a mixture of benzene, 19.6% phenol, 38.9% diphenylether and 41.4% unreacted 3,4-dichlorodiphenylether. No monochlorodiphenylether was detected. There was no evidence of any amino- substituted products or any disproportionation products. The reaction with added ethanol and sodium gave almost identical results: 20.4% phenol, 38.8% diphenylether and 40.4% unreacted 3,4-dichlorodiphenylether. No benzene was detected due to loss during concentration of the ethereal product mixture on a rotary evaporator.

The reaction of 3,4-dichlorodiphenylether with a six-fold molar ratio of sodium and ethanol to the starting material gave complete reduction and subsequent cleavage of the original material. The only products obtained were benzene and phenol. The recovery of phenol was only 70% of the theoretical amount due to losses during work-up.

The reaction with a six-fold molar amount of lithium and ethanol followed a different course. Here, the products were benzene, 57.8% phenol and 42.2% of an unresolved mixture (by gc/ms) of diphenylether

and a tetrahydrodiphenylether, presumably compound (XVIII) for the same reasons as given earlier. No unreacted 3,4-dichlorodiphenylether was detected by gc/ms.

No reaction occurred when 3,4-dichlorodiphenylether was treated with an equimolar amount of potassium amide in liquid ammonia. No disproportionation occurred, which is not surprising since there is no reported evidence of disproportionation of dichloro compounds under similar conditions.

There are two points of interest which need to be clarified at this time. These concern the course of the reactions and the formation of the dihydro- and tetrahydrodiphenylethers.

The course of the reactions seem to be reduction of the chlorine(s) from the chlorinated diphenylether to give diphenylether, followed by cleavage. All of the evidence obtained thus far gives strong proof as to this course of reaction. There remains, however, the possibility that cleavage could occur to give, in the case of 4-chlorodiphenylether, 4-chlorophenol and/or chlorobenzene and then these two compounds could, by reduction, give phenol and benzene respectively. It was decided to investigate the reaction of 4-chlorophenol with sodium in liquid ammonia to see if this is a possibility. Chlorobenzene has already been shown to be readily converted into benzene upon reaction with sodium and ethanol in liquid ammonia.

The reaction of 4-chlorophenol with sodium in liquid ammonia gave phenol as the only product in an isolated yield of 97%. A trace amount of unreacted 4-chlorophenol was also present. This reaction has been

reported elsewhere to give an 80% yield of phenol.[42] This result suggested that further studies in the course of the reactions of the chlorinated diphenylethers were required.

It was decided to investigate the reaction of 4-chloro-4'-methyl-diphenylether since the methyl group could give an effective handle to differentiate the two possible modes of reaction. Scheme 10 gives the expected products from reduction of 4-chloro-4'-methyldiphenylether followed by cleavage. The products are expected to be benzene, 4-methylphenol, phenol and toluene. These would occur from cleavage of 4-methyldiphenylether which is a reported reaction.[44]
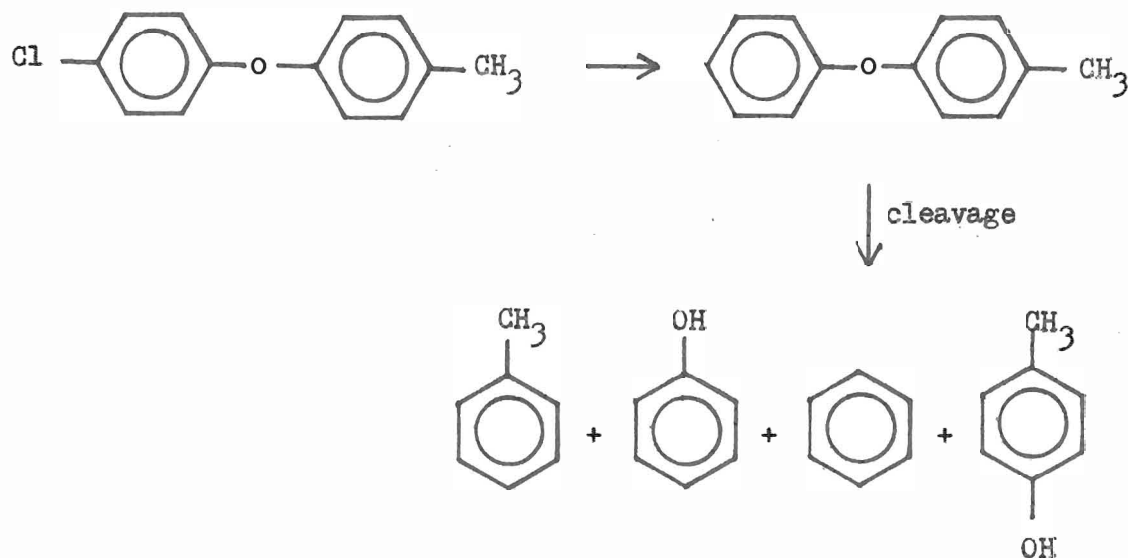


Scheme 10

The cleavage of 4-methyldiphenylether was also performed in this work and gave somewhat different results. A product mixture of 36.2% phenol, 55.3% 4-methylphenol and 8.5% of an unresolved mixture of 4-methyldiphenylether and a dihydro-4-methyldiphenylether. Benzene and toluene were not detected, probably due to losses during concentration of the product mixture. The structure of the dihydro-4-methyldiphenylether is probably given by (XX) and not (XXI) on the basis of mass spectral evidence.
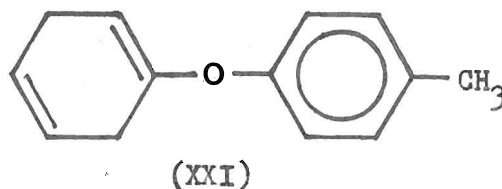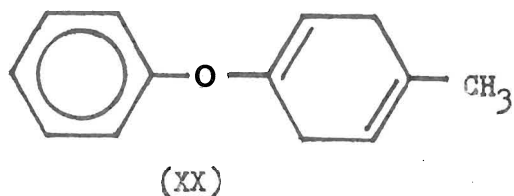


(XX) would be expected to give intense fragment ions at $m/e$ 93 for $(PhO-)^+$ and for the methyl-substituted reduced ring whereas (XXI) should give intense fragment ions at $m/e$ 95 and $m/e$ 91. No fragment ion was observed at $m/e$ 95, thus suggesting (XX) as the proper structure. Positive identification by mass spectrometry was not possible however since an unresolved mixture of the dihydro derivative and diphenylether was obtained.

The cleavage products of 4-methyldiphenylether are quite un-reactive under the conditions employed. 4-Methylphenol with sodium gave only unreacted starting material back. It is to be expected

that benzene and toluene would be reduced if any excess sodium was present.

Scheme 11 gives the expected products from cleavage of 4-chloro-4'-methyldiphenylether followed by further reduction.
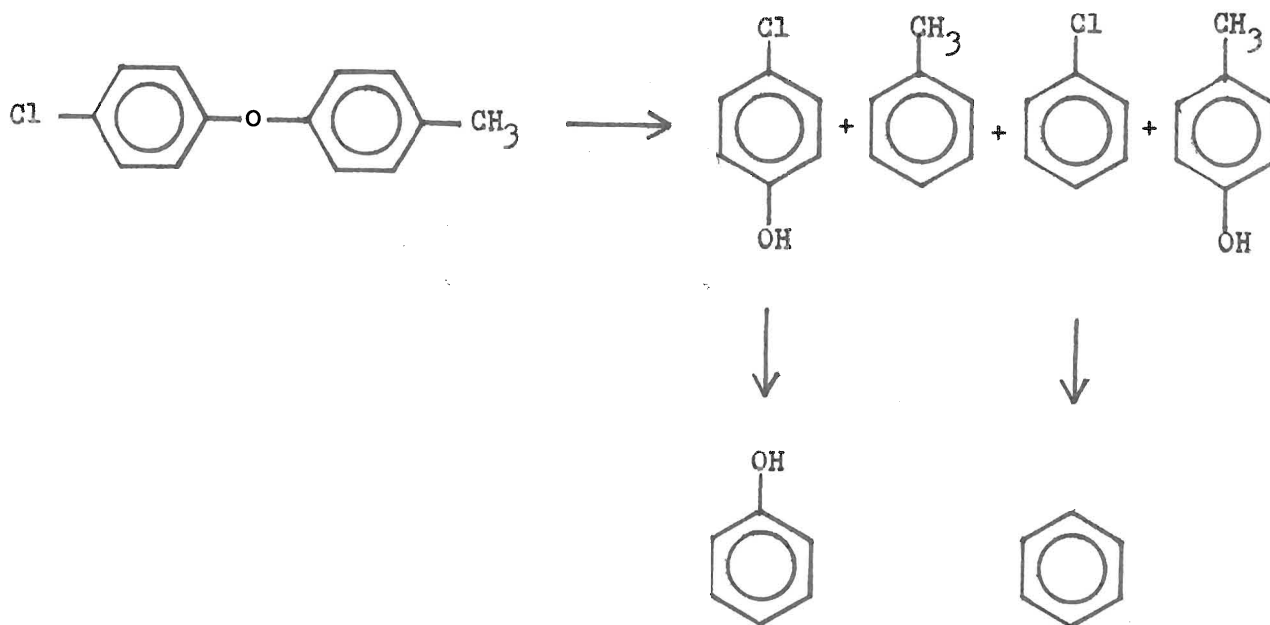
Scheme 11

Schemes 10 and 11 ultimately lead to the same product mixtures. The relative rates of the two reaction courses, represented in the two schemes, may be determined by looking at the product mixture. For example, if 4-chlorophenol is reduced slowly compared to reduction of 4-chloro-4'-methyldiphenylether followed by cleavage then some 4-chloro-phenol should be detected. If the reduction of 4-chloro-4'-methyl-

diphenylether is a fast process then the product distribution should be similar to that obtained for cleavage of 4-methyldiphenylether. The reaction of 4-chloro-4'-methyldiphenylether with sodium and ethanol in liquid ammonia gave a mixture of benzene, toluene, 8.2% phenol, 26.9% 4-methylphenol and 64.9% 4-methyldiphenylether. This is very similar to the distribution obtained by Sartoretto and Sowa[44] for the cleavage of 4-methyldiphenylether thus supporting a fast reduction of 4-chloro-4'-methyldiphenylether.

A possible method of distinguishing between the two possible modes of reaction of the chlorinated diphenylethers involves using a chlorinated diphenylether which has a methyl group in the chlorinated ring. A possibility may be 4-chloro-3,4',5-trimethyldiphenylether and Scheme 12 gives the expected products of the two reaction courses from this compound.

There would be no means of distinguishing the two courses of reaction based solely on products obtained if the cleavage products 1-chloro-2,6-dimethylbenzene (XXII) and 4-chloro-3,5-dimethylphenol (XXIII) were readily reduced under the reaction conditions. To test this, the reaction of 4-chloro-3,5-dimethylphenol with sodium and ethanol in liquid ammonia was carried out and gave a 96.6% yield of 3,5-dimethylphenol. No unreacted 4-chloro-3,5-dimethylphenol was detected by gc/ms. 1-Chloro-2,6-dimethylbenzene should be even more easily reduced since the phenol gives an activated aromatic ring making electron addition more difficult. It thus seems unlikely that Scheme 12 would differentiate between the possible courses of reaction of 4-chloro-
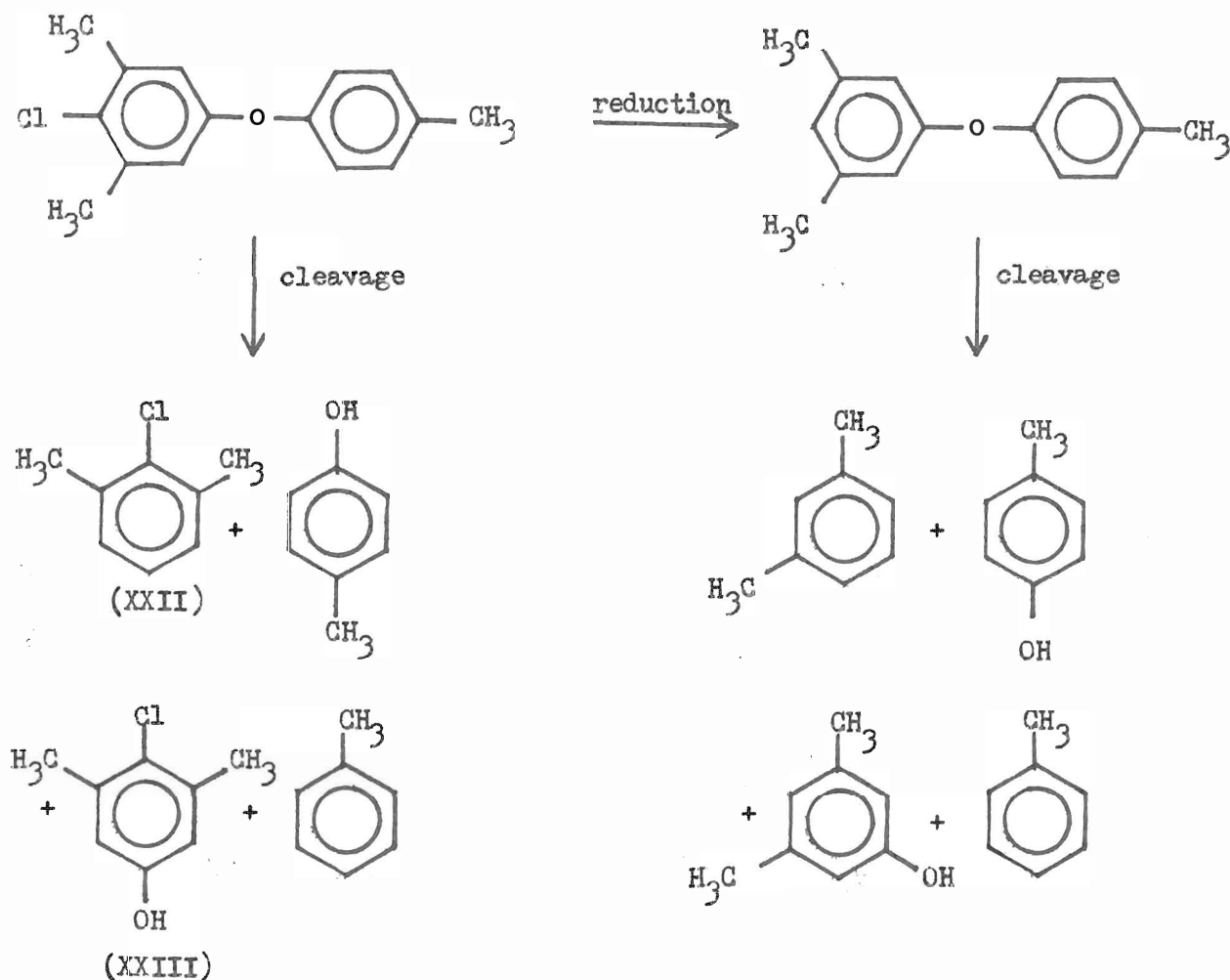
Scheme 12

3,4',5-trimethyldiphenylether. This compound was not prepared, but instead a different experiment was studied in a further attempt to gain an insight into the course of the reactions of the chlorinated diphenylethers.

An equimolar amount of 4-chlorodiphenylether and 4-chlorophenol was reacted with sodium and ethanol in liquid ammonia. 0.01 Moles of

each of the substrates were used and 0.021 moles of sodium was added, a quantity which was insufficient to react with all of the two substrates. The product mixture gave benzene, 20.6% phenol, 38.2% 4-chlorophenol, 31.0% diphenylether and 10.2% 4-chlorodiphenylether. These corresponded to 3.93 millimoles of phenol, 7.31 millimoles of 4-chlorophenol, 5.93 millimoles of diphenylether and 1.95 millimoles of 4-chlorodiphenylether. Thus, only 26.9% of the 4-chlorophenol was reduced whereas 80.5% of the 4-chlorodiphenylether was consumed. This result indicates that if cleavage of 4-chlorodiphenylether occurred, then some 4-chlorophenol should have been detected. No chlorophenols were detected in any reactions from the chlorinated diphenylethers, thus supporting a reaction scheme of reduction to diphenylether followed by cleavage to give benzene and phenol.

The reactions producing the dihydro- and tetrahydro- derivatives of diphenylether were further investigated. To briefly summarize, the reactions where these were formed were (a) 3-chlorodiphenylether with sodium and (b) 3,4-dichlorodiphenylether with lithium in ammonia respectively. As well, a dihydro-derivative of 4-methyldiphenylether was produced during reaction of 4-methyldiphenylether with sodium in liquid ammonia.

The reaction of diphenylether with sodium in liquid ammonia gave only the cleavage products benzene and phenol, consistent with reported results.[44] The reaction with lithium in liquid ammonia however, gave in addition, approximately 24% of an unresolved mixture (by gc/ms) of diphenylether, a dihydrodiphenylether and a tetrahydrodiphenylether.

The exact mass spectral assignments cannot be made conclusively however, since the mixture was unresolved. The ^{1}H nmr spectrum of the mixture showed strong olefinic (C=C-H) signals in the region $\delta$ 4.9 to $\delta$ 5.6 as well as strong methylene (CH$_2$) resonances at $\delta$ 2.9. To prove the identity of these compounds, the acid-catalyzed hydrolysis of the mixture was attempted. The dihydro- and tetrahydrodiphenylethers should have the structures (XVII) and (XVIII) respectively and thus contain enol ether groups which can be hydrolyzed under acidic conditions. Diphenylether should remain stable under these conditions. Scheme 13 gives the expected products from the hydrolysis.
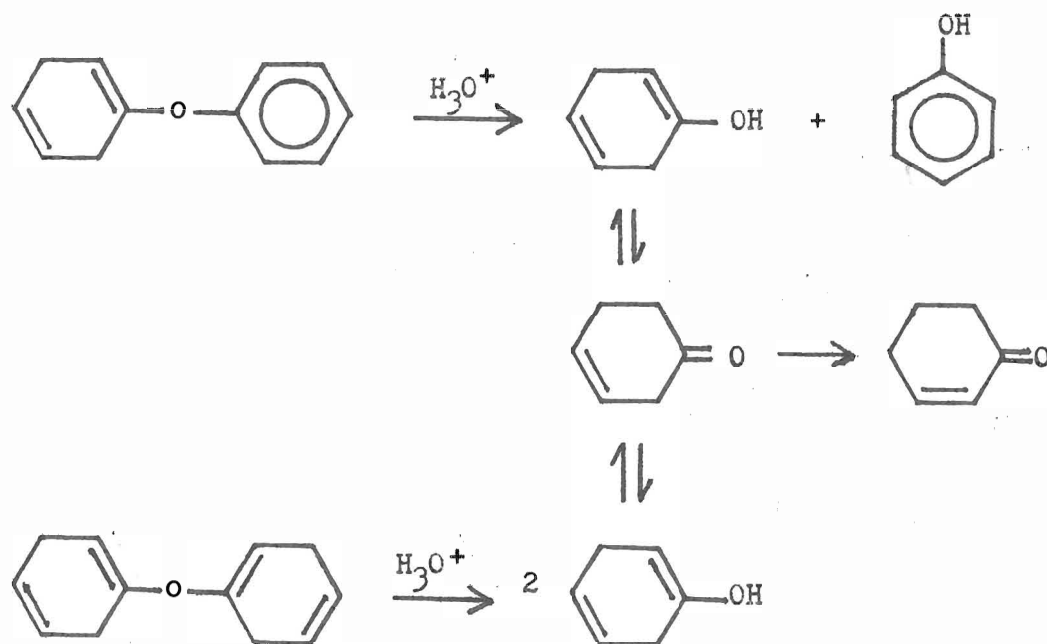


Scheme 13

The dihydro-derivative should give a mixture of 2-cyclohexenone and phenol, whereas the tetrahydro-derivative should give just 2-cyclo-hexenone.     The reaction was performed in 50% hydrochloric acid using a fifteen minute reflux.  Analysis of the product mixture indicated that phenol, 2-cyclohexenone and diphenylether were the only components present, thus confirming the original  existence of 2,5-dihydrodiphenyl-ether (XVII), 2,2',5,5'-tetrahydrodiphenylether (XVIII) and diphenyl-ether.  Unfortunately, 2-cyclohexenone and phenol were not resolved by gc/ms, making the relative amounts of these products undeterminable by gc/ms.

Most of the reported reductions of a phenoxy ring have been con-cerned with reductions of anisoles to give 2,5-dihydroanisoles.[31,33,34] A substituted anisole (XXIV) gave the 2,5-dihydroderivative (XXV) upon treatment with lithium in liquid ammonia.[75]



(XXIV)          (XXV)
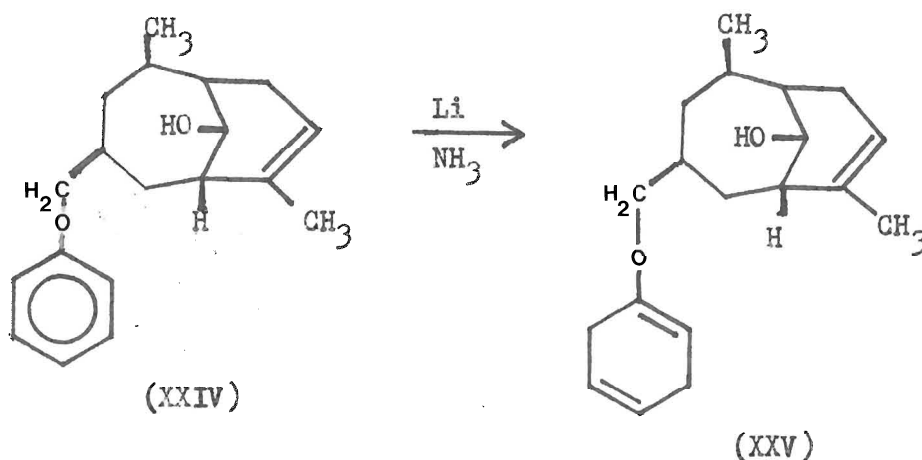
There is no reported evidence for the formation of dihydro- or tetrahydro-derivatives of diphenylether. All of the reported reductions of diphenylether with alkali metals in liquid ammonia have led exclusively to cleavage products.

Comparison of the compounds and the conditions which favoured the formation of the dihydro- and tetrahydro-derivatives of diphenylether indicated that a 3-chloro substituted diphenylether and lithium give more of the reduced products. The latter case is not too surprising since it has been found that the reactivity of the alkali metals towards cleavage is cesium > rubidium > potassium > sodium > lithium.[45]

The fact that the 3-chloro substitution appears to be important warrants some discussion. Other workers have determined that the first proton during the reduction of anisole adds to the 3 position.[31,33] Thus, a negative charge is partially localized at the 3-carbon during the initial addition of an electron. A chlorine atom at this position could conceivably partially stabilize this negative charge through inductive effects. This could be somewhat analogous to stabilization of certain sulphur ylides for example, such as the sulfonium ylides (XXVI).[76]

$$R-S-CH_2^{-}$$
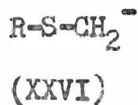
(XXVI)

In the case of the chlorinated diphenylethers, (XXVII) could be postulated as a possible intermediate. A somewhat analogous inter-
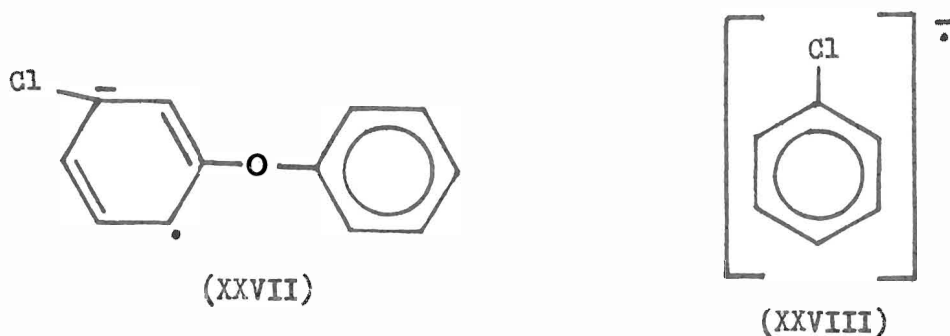
(XXVII)



(XXVIII)

mediate (XXVIII), proposed by Hudson[40] in the mechanism of halobenzene
reductions by metal/ammonia/alcohol reagents, could have a similar
stabilization from the chlorine atom.   The chlorine from (XXVII)
could than be lost, perhaps following protonation, leading ultimat-
ely to the 2,5-dihydro-derivative of diphenylether.

The reduction of 4-chlorophenol and 4-chloro-3,5-dimethylphenol
by sodium in liquid ammonia to give phenol and 3,5-dimethylphenol
respectively are interesting cases to consider.  The presence of a
phenolic group usually hinders reduction through formation of phenoxide
ions.  These would be strongly electron donating, thus inhibiting
electron addition to an aromatic ring.  Examples include the fact that
4-methylphenol was recovered unreacted after treatment with sodium in
liquid ammonia; 4-hydroxydiphenylether was not cleaved upon treatment
with sodium in liquid ammonia;[44] 2-hydroxydiphenylether gave no reaction
with sodium in liquid ammonia;[47] and reduction of 1-naphthol(XXIX) with
lithium and ethanol in liquid ammonia gave (XXX).[77]  However, chlorine
seems to be readily reduced out of phenolic rings.  The reduction of
4-chlorophenol was further studied to gain an insight into this.
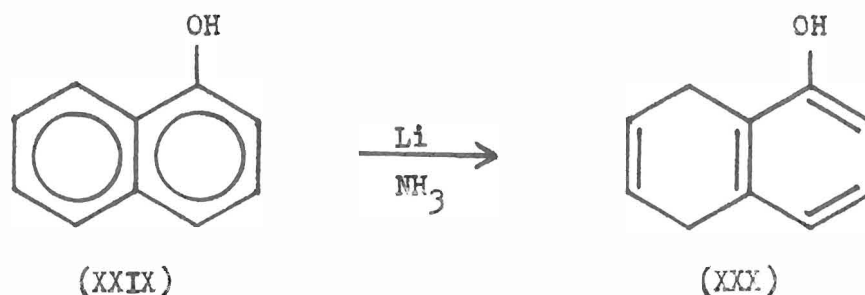
The sodium salt of 4-chlorophenol was prepared by treatment of 4-chlorophenol with methanolic sodium hydroxide. Reduction with sodium and ethanol in liquid ammonia gave complete conversion to phenol. The reaction was also tried by generating the phenolic salt *in situ*. 4-Chlorophenol was added to potassium amide in liquid ammonia and then sodium was added. Again, phenol was produced in high yield (92.7%).

It is not clear what the nature of the reacting species is. It is either the 4-chlorophenate salt or the 4-chlorophenol. There may be an equilibrium established between the two species as shown in equation (13), for the general case of phenol.

$$PhO^- + NH_3 \rightleftharpoons PhOH + NH_2^- \qquad \text{-----(13)}$$
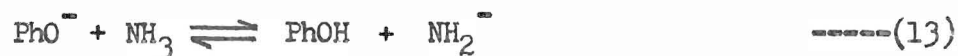
The equilibrium would normally lie to the left due to the high basicity of the amide ion, but since a large excess of ammonia is present, the true equilibrium will be pushed to the right. Thus, the reacting species may be the 4-chlorophenol itself. It would be expected to be more reactive than its salt since the aromatic ring in the phenol is less electron rich than in the salt.

The other compounds of environmental interest that were reduced were 4,5-dichloroveratrole and dibenzo-1,4-dioxin.

4,5-Dichloroveratrole (1,2-dimethoxy-4,5-dichlorobenzene) has a structure where the chlorines and the oxygens are in the same positions on the aromatic ring as in TCDD. The reaction with a two-fold molar ratio of sodium and ethanol in liquid ammonia gave veratrole, 4,5-dichloroveratrole plus a small amount of 4-chloroveratrole. The reaction with twice as much sodium gave veratrole with a very small amount of anisole present. In a control experiment, veratrole with sodium was a sluggish reaction and gave guaiacol (2-methoxyphenol), a small amount of anisole along with large amounts of unreacted veratrole. This supports the formation of anisole as being due to reduction of veratrole during the reaction of 4,5-dichloroveratrole, but the fact that guaiacol was not detected is somewhat surprising. It may have been left in the aqueous washings or else anisole was not produced from veratrole. It may have come from either 4,5-dichloroveratrole or from 4-chloroveratrole. This would involve demethoxylation and then dechlorination to give anisole.

The reaction of dibenzo-1,4-dioxin with a two-fold molar amount of sodium and ethanol in liquid ammonia gave a 98.9% yield of 2-hydroxy-diphenylether. This result was consistent with reported results.[47,78] The literature reports however were somewhat confusing since in the analyses the authors reported phenolic oils as products which left some doubt as to what the true products were. Thus, the reaction was repeated here.

In general therfore, the results in this work show that solutions of alkali metals in liquid ammonia are efficient methods for dehalo- genation of polyhalogenated aromatic compounds. In all of the compounds that were studied, virtually complete loss of halogen was observed.

From a practical standpoint, sodium is the metal of choice. It is more economical than the other alkali metals. Compared to lithium, which is also frequently used in metal/ammonia reductions, sodium is easier to handle than lithium. In the studies performed, the higher basicity of the sodium salts does not seem to result in secondary processes as long as an added proton source in present. There was virtually no difference in the dechlorinating abilities of sodium and lithium.

A wide variety of proton sources are used in metal/ammonia studies. These include ethanol, t-butanol, isoamyl alcohol and ammonium salts.[31] Ethanol seems to be particularly attractive since it is economical, easy to use and can act as a co-solvent to help dissolve certain organic compounds.

Dechlorination of TCDD by sodium and ethanol in liquid ammonia would seem to be a viable procedure. From analogy to the compounds studied, the probable course of reaction would be dechlorination to dibenzo-1,4-dioxin followed by cleavage to 2-hydroxydiphenylether as shown in Scheme (14). This would result in a non-chlorinated compound which could be safely disposed of by standard methods.

This method of degradation has the advantage in that it should be applicable to virtually any polyhalogenated organic pollutant and could
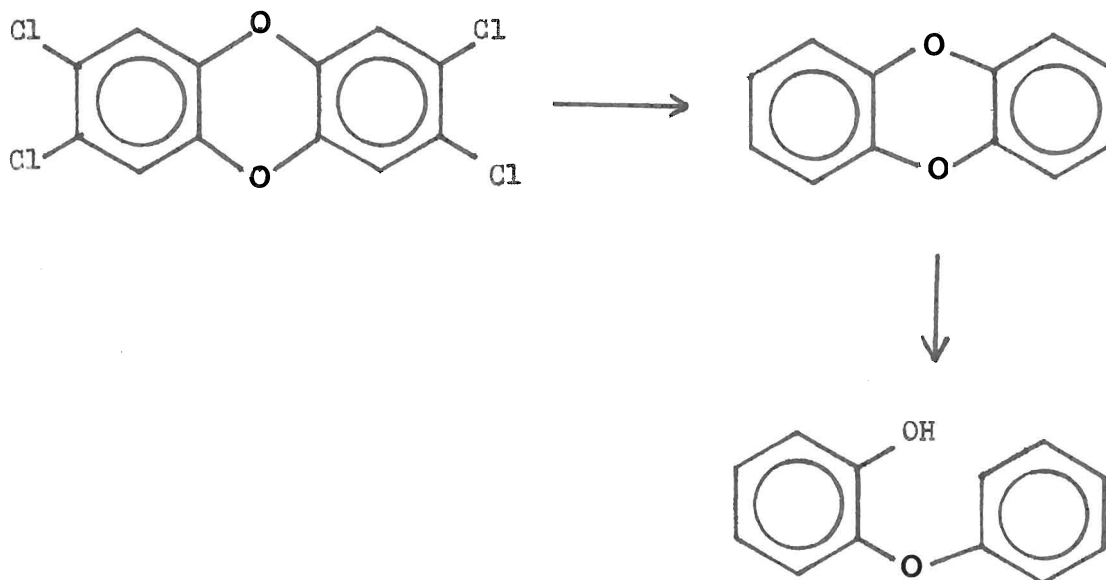
Scheme 14

thus be used for detoxification of polyhalogenated dibenzo-1,4-dioxins, polyhalogenated dibenzofurans and polyhalogenated biphenyls to name just a few. The method is effecient and utilizes fairly cheap reagents and is thus attractive from a practical standpoint.

Further work in this area should at first be concentrated on the reductions of further compounds. The reaction of 2-hydroxydiphenylether with sodium in liquid ammonia should be done since in the literature the authors again reported the presence of phenolic oils.[47,78] A possible compound to investigate is 4,5-dichloro-2-hydroxydiphenylether to see if this compound will dechlorinate. Of course, ultimately the reactions of chlorinated dibenzo-1,4-dioxins should be investigated, although the reaction of TCDD itself would be very dangerous due to its

high toxicity.

An interesting set of reactions to pursue may be the reductions of halogenated phenols to see if it is possible to remove halogens from a highly halogenated phenol. This may be applicable to the detoxification of pentachlorophenol.

From a pratical standpoint, the applicability of this method to industrial use must be considered although it is outside the scope of this work. Investigations into the possibility of solvent reuse may be worthwhile to pursue.

## Experimental

### Instruments and Methods

Melting points were determined on a Kofler Hot Stage apparatus and are uncorrected. Thin layer chromatography (tlc) was performed on 0.2 mm thick sheets of either silica gel 60 $F_{254}$ or alumina 13252. Column chromatography was performed on silica gel 100-200 mesh. Infra red spectra were obtained on a Perkin-Elmer model 710B grating infra red spectrophotometer. Samples were prepared as disks in potassium bromide unless noted otherwise and all values are expressed in units of $cm^{-1}$. $^1H$ Nuclear magnetic resonance spectra ($^1H$ nmr) were obtained on a Varian A-60, a Bruker WP-80 CW or a Bruker WP-60 FT nuclear magnetic resonance spectrometer. $^{13}C$ Nuclear magnetic resonance spectra ($^{13}C$ nmr) were obtained on a Bruker WP-60 FT spectrometer. In all cases the samples were dissolved in deuterochloroform unless noted otherwise and all chemical shifts are reported in units of $\delta$(ppm) downfield from internal tetramethylsilane (TMS).

Gas-liquid chromatography analyses (glc) were performed on either a Varian Aerograph model 90-P gas chromatograph equipped with a thermal conductivity detector using helium at 40 mL per minute as carrier gas, or on a Hewlett-Packard model 5700A gas chromatograph equipped with a flame ionization detector using nitrogen at 60 mL per minute as carrier gas. Columns were six feet long, $\frac{1}{4}$" o.d. and were made of stainless steel, copper or teflon. They were packed with 3% SE-30 on chromosorb

W HP 80/100, 3% Triton X-305 on chromosorb G HP 80/100, 4% Bentone-34 on chromosorb P 80/100 mesh or 10% Fluorad FC-431 on chromosorb W HP 80/100. Peak areas were determined by the cut-and-weigh method and were calibrated with standard mixtures of reference compounds.

Mass spectra were obtained on an AEI MS-30 double beam mass spectrometer equipped with a Data-General/Kratos DS-55 data system. Samples were introduced through either a direct probe or a gas chromatograph. Intensity ratios, normalized to the base peak are given in parentheses after each m/e value. For standard products such as benzene and phenol, the intensity ratios are only given for the first case and only the major fragments are quoted. Combined gas chromatography/mass spectrometry samples (gc/ms) were injected through a Pye Unicam Series 104 gas chromatograph using three or six foot long ¼" o.d. packed glass columns of 3% SE-30 on chromosorb W HP 80/100, 3% Triton X-305 on chromosorb G HP 80/100 or 3% Dexil 300 GC on Anakrom Q 80/100 P.

## Starting Materials and Reagents

Commercial samples and prepared starting materials were purified by recrystallization, distillation, sublimation, or column chromatography where necessary. Purity was checked by tlc, glc, or gc/ms as appropriate.

Reagents and solvents were purified prior to use by standard methods.[79]

Two different grades of copper metal were employed: electrolytic and electolytic dust grade.

Liquid ammonia was an anhydrous grade and was dried with sodium metal and distilled into the reaction flask immediately before use.

Alkali metals were scraped clean and were washed with ether or ethanol prior to additon to the reaction flask. Potassium amide was prepared by addition of potassium metal to liquid ammonia containing a small crystal of ferric nitrate. The mixture was stirred until a grey colour was produced.

## Standard Reaction Conditions

All reactions involving liquid ammonia were carried out in a 500 mL three-necked round-bottomed flask equipped with a mechanical stirrer and a cold-finger condenser fitted with a drying tube of solid potassium hydroxide or sodium hydroxide. Liquid ammonia was introduced into a second flask and was dried with sodium metal until a deep blue colour was maintained. The ammonia was then distilled into the reaction flask through a sodium hydroxide drying tube by heating on a water bath. The ammonia was condensed through the cold-finger condenser which was charged with dry ice/acetone. The starting material, as a solution in either ether or tetrahydrofuran, was then introduced via a dropping funnel. The alkali metal was then added in small pieces and the resulting solution was stirred until the blue colour disappeared, which was usually less than ten minutes. Ammonium chloride was then added and the reactions were worked up in one of two methods. Reactions in which no benzene was expected as a product were allowed to sit until

the ammonia evaporated; then 100 mL of water was added. Reactions in which benzene was expected were not evaporated, but 300 mL of water was cautiously added to the reaction mixture. The products were worked up with ether in both methods. Phenols were expected products in many reactions and were isolated from the other products by extracting the ethereal extracts with three 100 mL portions of 5% sodium hydroxide. This was combined with the original aqueous extract, the whole was acidified with hydrochloric acid and then extracted with three 100 mL portions of ether to isolate the phenol. In most reactions, therefore, an ether extract and an alkaline extract were obtained and are referred to as such in the experiments.

## Synthesis of Starting Materials

### Diphenyliodonium chloride

To a 500 mL three-necked round-botommed flask equipped with a mechanical stirrer was added benzene (45.0 mL, 0.5 mole), acetic anhydride (100 mL), and potassium iodate (53.5 g, 0.25 mole). The stirred mixture was cooled in an ice bath to below $5°C$. A solution of acetic anhydride (50 mL) and sulphuric acid (112.5 mL) was cooled to below $5°C$ and slowly added to the mixture over 30 minutes. The resulting solution was stirred overnight, poured onto 200 g of ice and then washed with ether (3 x 80 mL). The aqueous residue was treated with charcoal (2 x 10 g) and then ammonium chloride (50 g) in water (175 mL) was added. Cooling and filtering gave a white solid

and addition of a second portion of aqueous ammonium chloride afforded a
second crop. The combined material was recrystallized from methanol to
give diphenyliodonium chloride (32.8 g, 41.4%) as white crystals; m.p.
230-1°C (dec.) [lit.,[65] 228-9°C (dec.)]; m/e 205(4.9),204(73.8),114
(16.1),112(52.1),78(10.1),77(100.0),51(28.8); $\nu$(max): 1565,1460,1435,
990,740.


## 4,4'-Dimethyldiphenyliodonium chloride

A mixture of potassium iodate (53.5 g, 0.25 mole), toluene (46.08 g,
0.5 mole) and acetic anhydride (100 mL) were stirred in a salt water/ice
bath down to -5°C. An ice cold solution of acetic anhydride (50 mL) and
sulphuric acid (112.5 mL) was slowly added over 2 hours and the mixture
was stirred overnight. The work-up was identical to that for diphenyl-
iodonium chloride and afforded 48.53 g of crude material after one
treatment with ammonium chloride. Further treatment of the filtrate
with ammonium chloride failed to produce any more product. The crude
material was recrystallized from water and washed with cold ether to
give 4,4'-dimethyldiphenyliodonium chloride (14.11 g, 16.4%) as pink
crystals; m.p. 177-80°C (dec.) (lit.,[67] m.p. varies from 181°C to 229°C);
$^1$H nmr: $\delta$ 2.35(3H,3),7.1-8.0(8H,m); m/e 218(70.3),126(14.6),92(10.5),
91(100.0),65(27.7),39(12.1); $\nu$(max): 3050,2925,1575,1480,1225,1080,800.


## 4-Chlorodiphenylether (by Ullmann condensation)

a)    4-Chlorophenol (0.65 g, 5 mmole), bromobenzene (0.79 g, 5 mmole),
copper powder (1.6g, 25 mmole), and dimethylformamide (10 mL) were

refluxed for 4.5 hours. Water (25 mL) was added and the mixture was extracted with ether (3 x 25 mL). The combined ethereal extracts were washed with water (3 x 25mL), dried ($Na_2SO_4$), and concentrated to give a yellow liquid (1.18 g). Combined gc/ms indicated that the major component was unreacted starting material (m/e 130,128,65), with a minor amount of 4-chlorodiphenylether; m/e 206(32.7),205(15.4),204 (100.0),169(16.2),141(73.6),115(13.5),77(77.4),51(38.6).

The synthesis was repeated except that the copper was activated by the method of Vogel.[80] This still gave only a small amount of the desired product as indicated by gc/ms data.

b)     1,4-Dichlorobenzene (2.94 g, 0.02 mole), phenol (1.88 g, 0.02 mole), potassium hydroxide (1.12 g, 0.02 mole), toluene (3 mL), and dimethylsulphoxide (15 mL) were heated for 5 hours at 135°C while the water produced was removed azeotropically with toluene. The resulting mixture was filtered and distilled to remove solvents, leaving a gummy residue. Extraction with chloroform (3 x 25 mL) gave a yellow oil (0.42 g). Analysis by gc/ms indicated that only a small amount of 4-chlorodiphenylether was produced.

### 4-Chlorodiphenylether

A mixture of 4-chlorophenol (6.43 g, 0.05 mole), potassium hydroxide (2.81 g, 0.05 mole), diphenyliodonium chloride (15.83 g, 0.05 mole), and water (400 mL) was stirred under reflux for 24 hours. The mixture was extracted with ether (3 x 100 mL) and the combined

ethereal extracts were washed with 5% sodium hydroxide (2 x 100 mL),
water (2 x 100 mL), dried ($Na_2SO_4$), and concentrated to give a yellow
liquid (17.65 g). Fractional distillation of 17.03 g gave a colourless
liquid (7.73 g, 78.2%); b.p. 144°C/24 mm (lit.,[81] 161-2°C/19 mm). Gc/ms
indicated a small amount of iodobenzene was present. The material was
chromatographed using hexane as eluent to give pure 4-chlorodiphenyl-
ether; ^{1}H nmr: $\delta$ 6.8-7.45(m); ^{13}C nmr: $\delta$ 119.0,120.1,123.7,128.2,129.8,129.9,
156.1,157.0; m/e 206(32.4),205(15.0),204(100.0,M$^+$),169(12.4),141(64.9),
77(92.4),75(21.2),51(56.5); $\nu$(max): (liquid film): 3050,1585,1480,1250,
1165,1090,830,795,760.

## 3-Chlorodiphenylether

3-Chlorophenol (6.43 g, 0.05 mole), potassium hydroxide (2.81 g,
0.05 mole), diphenyliodonium chloride (15.83 g, 0.05 mole), and water
(400 mL) were stirred under reflux for 24 hours, and the mixture was
then extracted with ether (3 x 100 mL). The combined ethereal extracts
were washed with 5% sodium hydroxide (2 x 100 mL), water (2 x 100 mL),
dried ($Na_2SO_4$), and concentrated to give a yellow liquid (17.63 g).
Then 17.10 g was fractionally distilled to remove iodobenzene, leaving
7.86 g (79.2%) of material which was chromatographed using hexane as
eluent to afford pure 3-chlorodiphenylether; b.p. 155°C/20 mm (lit.,[81]
168-9°C/30 mm); ^{13}C nmr: $\delta$ 116.7,118.9,119.5,123.2,124.0,130.0,130.5,
135.2,156.5,158.5; m/e 206(32.0),204(100.0,M$^+$),169(29.0),141(59.2),
77(54.9),51(51.3); $\nu$(max) (liquid film): 3050,1585,1490,1470,1230,910,
760,690.

### 3,4-Dichlorodiphenylether

3,4-Dichlorophenol (8.15 g, 0.05 mole), potassium hydroxide (2.81 g, 0.05 mole), diphenyliodonium chloride (15.83 g, 0.05 mole), and water (400 mL) were stirred under reflux for 24 hours. Extraction with ether gave a yellow liquid (18.0 g). Fractional distillation of 17.31 g gave a colourless liquid (7.98 g, 69.4%); b.p. 181°C/25 mm (lit.,[82] 160-3°C/ 17 mm). The material was chromatographed using hexane as eluent to give pure 3,4-dichlorodiphenylether; $^{13}$C nmr: $\delta$ 117.9,119.4,120.3,124.3, 126.4,130.1,131.0,134.1,156.1,156.7; m/e 242(10.1),240(62.1),239(17.1), 238(100.0,M$^+$),202(10.3),177(13.3),175(41.0),168(29.6),139(10.4),77(78.7), 51(35.4); $\nu$(max) (liquid film): 3050,1580,1475,1275,1225,1200,1150,1125, 1075,1030,925,865,820,765,690.

### 4-Chloro-4'-methyldiphenylether

4-Chlorophenol (5.21 g, 40.5 mmole), potassium hydroxide (2.27 g, 40.5 mmole), 4,4'-dimethyldiphenyliodonium chloride (13.95 g, 40.5 mmole), and water (300 mL) were stirred under reflux for 24 hours. Work-up with ether as before gave an orange-brown liquid (12.59 g). Then 11.10 g was fractionally distilled to remove 4-iodotoluene, leaving 5.90 g (75.6%) of a brown solid. The material was chromatographed using chloroform as eluent and then recrystallized from ethanol to afford pure 4-chloro-4'-methyldiphenylether as cream plates; m.p. 55.5°C (lit.,[51] 56°C); $^1$H nmr: $\delta$ 2.2(3H,s),6.6-7.2(8H,m); m/e 220(27.1),219 (14.0),218(85.3,M$^+$),217(8.1),155(15.4),92(7.7),91(100.0),77(10.0),65 (24.2),63(8.1),51(8.7); $\nu$(max): 2900,1600,1510,1485,1280,1260,1090,825.

## 4-Methyldiphenylether

4-Methylphenol (5.41 g, 0.05 mole), potassium hydroxide (2.81 g, 0.05 mole), diphenyliodonium chloride (15.83 g, 0.05 mole), and water (400 mL) were stirred under reflux for 24 hours. Work-up with ether in the usual manner gave a yellow liquid (17.94 g). Fractional distillation of 16.85 g gave 4-methyldiphenylether (4.60 g, 53.2%) as a colourless liquid; b.p. 160°C/32 mm (lit.,[44] 114°C/6 mm); $^1$H nmr: $\delta$ 2.3(3H,s),6.7-7.3(9H,m); m/e 185(26.0),184(100.0,M$^+$),183(30.0),91(96.2), 77(33.4),65(22.9),51(28.1); $\nu$(max) (liquid film): 3040,2910,1590,1490, 1230,870,825,750,690.

## 4,5-Dichloroveratrole

Sulphuryl chloride (19.0 mL) was added over 1 hour to stirred veratrole (13.82 g, 0.1 mole) at 15-20°C. Stirring was continued at this temperature for 1 hour and then at 80°C for 1.5 hours. The excess of sulphuryl chloride was remover in vacuo (28 mm) and the residue was recrystallized from ethanol to give 4,5-dichloroveratrole (17.43 g, 84.2%) as white needles; m.p. 85°C (lit.,[83] 83.5°C); $^1$H nmr: $\delta$ 6.95(s); m/e 210(11.3),208(89.9),206(100.0,M$^+$),193(43.6),191(69.3),165(24.8), 163(39.9),147(10.3),145(14.3),135(11.6),133(16.0),130(18.8),129(15.6), 128(58.9),127(36.4),115(14.0),113(46.2),101(25.6),99(54.8),97(23.2), 85(21.0); $\nu$(max):3000-2900,1500,1430,1360,1250,1210,1180,1025,920, 845,795,675.

## Dibenzo-1,4-dioxin

Sodium metal (0.46 g, 0.02 mole) was dissolved in ethanol (10 mL) and 2-bromophenol (3.46 g, 0.02 mole) was added. The ethanol was

evaporated to leave a white solid to which was added potassium carbonate (1.38 g), copper powder (0.15 g), and dimethylformamide (10 mL) and the mixture was then refluxed for 18 hours. Water (50 mL) was added and the product was extracted into ether (3 x 100 mL). The combined ethereal extracts were washed with 5% sodium hydroxide (3 x 100 mL), water (3 x 100 mL), dried (MgSO$_4$), and concentrated to give the crude material (1.02 g, 55.4%) as a yellow solid. Recrystallization of combined materials from several preparations gave dibenzo-1,4-dioxin as brown needles; m.p. 119-20°C (lit.,[84] 120-2°C); m/e 185(13.2),184(100.0,M$^+$), 128(38.7),127(11.4),102(16.1),92(17.7),63(12.1),52(14.4),51(17.3).

## Reactions

## Reductions of Polychlorobenzenes

### Chlorobenzene

Chlorobenzene (1.69 g, 0.015 mole) and ethanol (1.45 g, 0.0315 mole) were added to ammonia (150 mL). Sodium metal (0.72 g, 0.0315 mole) was added over 5 minutes and the mixture was stirred for 10 minutes. Ammonium chloride (1.68 g, 0.0315 mole) was added, followed by water (450 mL). Standard work-up gave a yellow liquid (1.27 g). The liquid was shown by gc/ms to be primarily ether with a small amount of benzene [m/e 79(7.3),78(100.0,M$^+$),77(25.0),52(18.7),51(14.3),39(10.0)] present; $^1$H nmr: $\delta$ 7.3(s). Integration of the nmr spectrum indicated about 8% benzene was present corresponding to an 8.7% yield based upon the original amount of chlorobenzene added. Benzene was also present (gc/ms) in the ethereal distillate from the work-up.

## Chlorobenzene + Bromobenzene

An equimolar mixture (0.01 mole each) of the two halobenzenes in ether (20 mL) and ethanol (1.45 g, 0.021 mole) was added to ammonia (100 mL). Addition of sodium metal (0.72 g, 0.021 mole) over 5 minutes gave a colourless solution. Ammonium chloride (1.12 g, 0.021 mole) was added followed by water (300 mL). Standard work-up gave a yellow liquid (0.27 g). Gc/ms indicated the presence of a mixture of benzene: m/e 79,78,77,52,51,39; chlorobenzene: m/e 114(33.0),112(100.0,M$^+$),77 (64.0),51(12.3),50(9.6); and bromobenzene: m/e 158(79.3),156(80.4,M$^+$), 77(100.0),51(21.3),50(13.4). Glc on 3% SE-30 at 60-200°C programmed at 16°C/min. with an FID detector gave 45.5% chlorobenzene and 54.5% bromobenzene.

## Chlorobenzene + Fluorobenzene

The procedure followed was identical to the previous reaction. Vigorous frothing occurred upon addition of the sodium. Gc/ms of the resulting ethereal solution indicated that three components were present. The first two components were unresolved and were benzene: m/e 78,77,51, 50,39; and fluorobenzene: m/e 97(9.0),96(100.0,M$^+$),95(10.5),70(25.0), 50(21.1). The third component was chlorobenzene: m/e 114,112,77,51,50. The mixture was further evaporated to give an orange liquid (0.38 g) which gave mostly chlorobenzene as shown by gc/ms.

## 1,2,3,4-Tetrachlorobenzene

1,2,3,4-Tetrachlorobenzene (2.16 g, 0.01 mole) in ether (30 mL) and ethanol (3.87 g, 0.084 mole) was added to ammonia (100 mL). Sodium metal (1.93 g, 0.084 mole) was added over 10 minutes and the mixture

was stirred for 5 minutes. Ammonium chloride (4.49 g, 0.084 mole) was added, followed by water (300 mL). Standard work-up gave a yellow liquid; $^1$H nmr: $\delta$ 2.62(s),5.56(s),7.23(s). Gc/ms indicated the presence of benzene: m/e 78,77,52,51; and 1,4-cyclohexadiene: m/e 80(79.4,M$^+$), 79(100.0),78(16.2),77(65.3),52(12.9),51(16.9). Comparison of the $^1$H nmr spectral intensities indicated that 1,4-cyclohexadiene was the major component.

## 1,2,3,5-Tetrachlorobenzene

The procedure followed was identical to the previous reaction and gave a yellow ethereal extract; $^1$H nmr: $\delta$ 5.56(s),7.14(s),7.25(s). The signal at $\delta$ 2.6 was masked by strong sidebands from the ether signal. Gc/ms indicated that the mixture consisted of benzene: m/e 78,77,52, 51,39; 1,4-cyclohexadiene: m/e 80(81.2),79(100.0),78(19.4),77(71.3), 52(17.9),51(20.2); plus a trace amount of unreacted starting material: m/e 220,218,216,214,181,179,109,108.

## 1,2,4,5-Tetrachlorobenzene

1,2,4,5-Tetrachlorobenzene (2.16 g, 0.01 mole) in ether (30 mL), tetrahydrofuran (20 mL), and ethanol (3.87 g, 0.084 mole) was added to ammonia (100 mL) to give a white slurry. Sodium metal (1.93 g, 0.084 mole) was added over 10 minutes and the mixture was stirred for 5 minutes to give a white solution. Ammonium chloride (4.49 g, 0.084 mole) was added, followed by water (300 mL). Standard work-up gave a yellow liquid (0.15 g). Gc/ms indicated that the liquid was composed

of three compounds: benzene: m/e 78,77,52,51; 1,4-cyclohexadiene: m/e 80(74.4),79(100.0),78(26.7),77(72.7),52(13.1),51(15.1); and un-reacted starting material: m/e 220,218,216,214,183,181,179,145,143. The quantity 0.15 g accounts for a 93% reduction of the original material.

## Pentachlorobenzene

Pentachlorobenzene (5.1 g, 0.02 mole) in tetrahydrofuran (40 mL) was added to ammonia (150 mL). Sodium metal (1.0 g, 0.0435 mole) was added over 10 minutes to give a green-brown solution, which was then stirred for 4 hours. Ammonium chloride (2.33 g, 0.0435 mole) was added and the solution was left to allow the ammonia to evaporate. Water (100 mL) was added and the mixture was extracted with ether (3 x 50 mL) and then with chloroform (3 x 50 mL). The combined organic extracts were washed with water (3 x 50 mL), dried (MgSO$_4$), and concentrated to give a dark orange-brown solid (4.34 g); $^1$H nmr: $\delta$ 7.25(s),7.38(s), 7.53(s). Gc/ms and glc indicated that the solid was a mixture of 1% 1,3,5-trichlorobenzene: m/e 184(12.0),182(38.8),180(41.6,M$^+$),145(17.9), 109(13.2),74(16.2),71(100.0),70(29.3); 17.7% of one or both of 1,2,3,5- or 1,2,4,5-tetrachlorobenzene(s): m/e 220(10.2),218(47.7),216(100.0), 214(77.5,M$^+$),181(19.0),179(19.4),143(10.9),109(10.3),108(12.2),74(10.5); 72.9% of unreacted pentachlorobenzene: m/e 254(20.5),252(64.5),250(100.0), 248(62.8,M$^+$),217(9.6),215(19.3),213(15.3),108(14.8); 8.5% hexachloro-benzene: m/e 288(33.7),286(79.0),284(100.0),282(50.8,M$^+$),251(16.6), 249(25.7),247(15.9),142(21.3); plus trace amounts of two unidentified

materials having m/e 309(14.0),307(27.5),305(23.8),237(63.6),236(19.5),
235(100.0),201(13.4); and m/e 343(24.9),341(37.6),339(23.4),273(31.9),
271(98.4),270(21.5),269(100.0),51(18.9); representative of 3 and 4
chlorine atoms per compound respectively.


## Pentachlorobenzene

Pentachlorobenzene (2.55 g, 0.01 mole) in tetrahydrofuran (20 mL)
and ethanol (4.85 g, 0.105 mole) was added to ammonia (100 mL) to give
a white slurry. Sodium metal (2.42 g, 0.105 mole) was added over 5
minutes which resulted in vigorous frothing. The mixture was stirred
for 30 minutes and the blue colour was discharged by addition of am-
monium chloride (5.36 g, 0.105 mole). Standard work-up gave an ethereal
liquid; $^1$H nmr: $\delta$ 2.58(s), 5.56(s). Gc/ms indicated that only 1,4-cyclo-
hexadiene: m/e 80(100.0),79(98.3),78(18.6),77(25.3),51(16.2) was
present.


## Hexachlorobenzene

Hexachlorobenzene (5.7 g, 0.02 mole) in tetrahydrofuran (150 mL)
was added to ammonia (100 mL) to give a white slurry. Sodium metal
(1.0 g, 0.0435 mole) was added over 10 minutes and the mixture was
stirred for 4 hours to give a brown solution. Ammonium chloride
(2.33 g, 0.0435 mole) was added and the mixture was left overnight.
Water (100 mL) was then added and the mixture was extracted with ether
(3 x 50 mL). A brown solid remained which was filtered and washed
with water to give unreacted hexachlorobenzene (2.25 g): m/e 288(34.1),

286(79.8),284(100.0),282(51.3),251(16.3),249(25.9),247(15.6),214(12.4).
The filtrate was extracted with ether (3 x 50 mL) and the ethereal
extracts were combined with the original ethereal extracts and the
whole was washed with water (3 x 100 mL), dried (MgSO$_4$), and concen-
trated to give a dark brown solid (1.93 g). Recrystallization from
chloroform gave an additional 0.81 g of unreacted hexachlorobenzene.
The total yield of recovered hexachlorobenzene was 4.18 g (73.3%). The
mother liquor was concentrated to give a brown solid (0.97 g). Gc/ms
indicated that hexachlorobenzene was the major component, along with
small amounts of pentachlorobenzene: m/e 254(19.7),252(62.5),250(100.0),
248(61.6),217(10.7),215(22.9),213(18.1),180(7.9),178(8.9),143(9.7),
108(18.9),73(10.4); diphenylamine: m/e 170(11.6),169(100.0,M$^+$),168
(56.5),167(35.9),77(15.1),66(13.1),51(18.2); tetrachloroaniline(s):
m/e 235,233,231,229; plus unidentified material containing 5 chlorine
atoms each and having m/e 270(21.0),268(66.6),266(100.0),262(61.4),
230(10.8),167(15.5),165(14.9); m/e 298,296,294,292; and m/e 343(14.4),
341(31.3),339(20.2),273(30.9),272(14.4),271(100.0),270(19.8),269(97.8),
234(13.2),77(13.6),51(19.6). Glc gave 3.4% pentachlorobenzene, 11.9%
diphenylamine, 43.3% hexachlorobenzene and 41.4% of the unknown com-
pounds. Inclusion of the isolated hexachlorobenzene gives 1.2% penta-
chlorobenzene, 4.1% diphenylamine, 80.7% hexachlorobenzene and 14.1%
of a mixture of unknown compounds.

## Disproportionation of Polychlorobenzenes

## 1,2,3,4-Tetrachlorobenzene

1,2,3,4-Tetrachlorobenzene (4.32 g, 0.02 mole) in ether (30 mL) was added to a solution of potassium amide (0.01 mole) in ammonia (150 mL). The mixture was stirred for 4 hours and then left overnight. Water (100 mL) was added, the solution was saturated with sodium chloride and extracted with ether (3 x 50 mL). The combined extracts were washed with water (2 x 50 mL), dried (MgSO$_4$), and concentrated to give a red solid (3.73 g). Gc/ms and glc indicated the presence of 3.7% 1,2,4-trichlorobenzene: $m/e$ 184,182,180,147,145,111,108; 92.5% unreacted 1,2,3,4-tetrachlorobenzene: $m/e$ 218,216,214,181,179; 3.8% pentachlorobenzene: $m/e$ 254,252,250,248,218,217,216,215,214; plus trace amounts of either 1,2,3,5- or 1,2,4,5-tetrachlorobenzene, trichloroaniline ($m/e$ 199,197,195), and unidentified materials containing 4 chlorine atoms and having $m/e$ 236,234,232,230 and $m/e$ 262,260,258.

## 1,2,3,5-Tetrachlorobenzene

1,2,3,5-Tetrachlorobenzene (4.32 g, 0.02 mole) in ether (30 mL) was added to a solution of potassium amide (0.01 mole) in ammonia (150 mL) and the mixture was stirred for 4 hours. Ammonium chloride (0.53 g, 0.01 mole) was added and the mixture was left overnight. Water (100 mL) was added and the solution was saturated with sodium chloride and extracted with ether (3 x 50 mL). The aqueous extract was then extracted with chloroform (3 x 50 mL). The combined organic extracts were washed with water (2 x 50 mL), dried (MgSO$_4$), and concentrated to yield a red solid (3.75 g). Gc/ms and glc indicated that the product was

mainly unreacted 1,2,3,5-tetrachlorobenzene ($m/e$ 220,218,216,214) with traces of 1,3,5-trichlorobenzene ($m/e$ 184,182,180) and pentachlorobenzene ($m/e$ 254,252,250,248).

## Analysis of Pentachlorobenzene Disproportionation

2.0 g of the crude product (m.p. 78-80°C) obtained from the treatment of pentachlorobenzene with potassium amide (experiment done by McCullough[57]) was dissolved in hot ethanol and cooled in an ice bath to afford tan crystals (1.0 g); m.p. 84-5°C, of pentachlorobenzene. The mother liquor gave 0.75 g of a light brown solid. Gc/ms and glc analyses showed the presence of three components, which were 6.4% of a tetrachlorobenzene(s), 84.9% pentachlorobenzene, and 8.7% hexachlorobenzene. The ^{1}H nmr spectrum included signals at $\delta$ 7.21(s), 7.35(s), and 7.50(s) with the signal at $\delta$ 7.50 being much stronger than the other two.

In an attempt to separate the mixture, the material was chromatographed using methylene chloride as eluent. Three fractions, each showing a single spot on tlc were obtained, but glc showed that a mixture of the three components was present in each fraction.

## Further Analysis of 1,2,3,4- and 1,2,3,5-Tetrachlorobenzene Disproportionation

The crude products from these two disproportionation runs (given on pages 93 and 94) were fractionally crystallized from ethanol.

3.64 g of crude material from 1,2,3,4-tetrachlorobenzene plus

potassium amide gave 0.8 g of 1,2,3,4-tetrachlorobenzene; m.p. 46.5-47.5°C, and 1.0 g of a mother liquor. Glc identified 1,2,4-trichlorobenzene, 1,2,3,4-tetrachlorobenzene, and pentachlorobenzene in the mother liquor.

3.33 g of crude material from 1,2,3,5-tetrachlorobenzene with potassium amide gave 1.5 g of 1,2,3,5-tetrachlorobenzene; m.p. 50-1°C. Glc of this and of the mother liquor both showed only a single peak was present.

## Separation of Polychlorobenzenes by Glc

A variety of packed columns and temperature conditions were used in attempts to separate the individual isomers of the trichloro- and tetrachlorobenzenes. Standard mixtures were made up and were used under the different conditions. Table 7 gives some representative results.

Glc analyses of the disproportionation products obtained by McCullough[57] in this laboratory were also performed and are reported in Table 8. In addition, the results were calibrated with standard reference compounds.

## Calibration of Glc Data

The quantitative results were calibrated using standard mixtures of the polychlorobenzenes. In general, product mixtures having nearly equal amounts of each polychlorobenzene in question gave more accurate measurements of peak areas. Cases in which there was one dominant

| Chlorobenzene Isomer | Retention Time (min.) for each Column[a] | | |
|---|---|---|---|
| | A | B | C |
| 1,2,3-Cl$_3$- | 4.65 | 4.63 | 5.43 |
| 1,2,4-Cl$_3$- | 4.45 | 3.94 | 2.28 |
| 1,3,5-Cl$_3$- | 4.06 | 2.95 | 1.42 |
| 1,2,3,4-Cl$_4$- | 5.94 | 8.37 | 7.48 |
| 1,2,3,5-Cl$_4$- | 5.63 | 5.91 | 3.23 |
| 1,2,4,5-Cl$_4$- | 5.67 | 6.00 | 3.46 |

a: A- 3% SE-30 on chromosorb W; 80°C for 2 min. then up to 180°C at 8°C/min.

B- 10% Fluorad FC-431 on chromosorb W at 172°C.

C- 4% Bentone-34 on chromosorb P at 172°C.

Table 7: Separation of Polychlorobenzenes by Glc

| Chlorobenzene Isomer | Reactant[a] | Retention Times[b] (min.) |
|---|---|---|
| 1,2,3,5-Cl$_4$- | NaNH$_2$ | 3.25 |
| 1,2,3,5-Cl$_4$- | KNH$_2$ | 3.35 |
| 1,2,3,4-Cl$_4$- | " | 2.16,3.74[c],5.41 |
| 1,2,3,4-Cl$_4$- | " | 3.54 |
| 1,2,4,5-Cl$_4$- | " | 3.35 |
| Cl$_5$ | " | 3.44,[d]6.10,10.83[d] |
| Cl$_5$ | PhNHK | 5.51 |
| 1,2,4,5-Cl$_4$- | " | 3.25 |
| 1,2,3,4-Cl$_4$- | " | 1.57,4.53,7.28 |
| 1,2,3,5-Cl$_4$- | " | 1.79,2.36,4.13,[c]5.51,6.10,8.07 |
| 1,2,3,5-Cl$_4$- | " | 1.67,3.74,5.91,7.87 |
| 1,2,4,5-Cl$_4$- | KNH$_2$ | 3.44 |
| 1,2,3,5-Cl$_4$- | KNH$_2$ | 3.05 |
| blank | PhNHK | 1.57 |

a: Experiments performed by McCullough[57]

b: Column- 3% SE-30 on chromosorb W at 172°C.

c: Major product

d: Trace amount.

Table 8: Glc of Disproportionation Products

| Standard Chlorobenzene Isomer | Retention Time[a] (min.) |
|---|---|
| 1,2,3-Cl$_3$- | 2.95 |
| 1,2,4-Cl$_3$- | 2.36 |
| 1,3,5-Cl$_3$- | 2.26 |
| 1,2,3,4-Cl$_4$- | 4.13 |
| 1,2,3,5-Cl$_4$- | 3.44 |
| 1,2,4,5-Cl$_4$- | 3.15 |
| Cl$_5$ | 5.41 |
| Cl$_6$ | 11.32 |

a: Same conditions as for Table 8.

Table 9: Reference Compounds for Disproportionation Products

isomer gave larger errors in the areas of the minor peaks. The
relative areas were calculated by the cut-and-weigh method. The
following two examples are representative of the calibration results.

| Chlorobenzene Isomer Mixture (wt.%) | Glc Area[a](%) |
|---|---|
| 1,3,5-Cl$_3$- (5) | 5.6 |
| 1,2,4,5-Cl$_4$- (90) | 88.0 |
| Cl$_5$ (5) | 6.4 |
| | |
| 1,2,4,5-Cl$_4$- (10) | 9.9 |
| Cl$_5$ (80) | 80.5 |
| Cl$_6$ (10) | 9.6 |

a: Column- 3% SE-30 on chromosorb W at 175°C

## Reactions of Chlorodiphenylethers

All reactions were run in liquid ammonia.

Run 1: 4-Chlorodiphenylether + Sodium

4-Chlorodiphenylether (3.07 g, 0.015 mole) in ether (15 mL) was
added to ammonia (150 mL). Sodium metal (0.72 g, 0.0315 mole) was
added over 10 minutes to produce a brown solution which was stirred

for 1 hour. Ammonium chloride (1.68 g, 0.0315 mole) was added and the mixture was left overnight. Water (100 mL) was added and the product was worked up in ether in the usual manner to give a brown liquid (2.0 g). Gc/ms indicated the presence of phenol: $m/e$ 94(100.0,$M^+$), 66(28.4),65(20.5),39(16.5); diphenylether: $m/e$ 171(12.8),170(100.0,$M^+$), 169(22.3),142(39.1),141(52.6),115(14.0),77(64.5),51(63.3); a small amount of an aminodiphenylether(s): $m/e$ 186(13.7),185(100.0,$M^+$),156 (19.5),109(13.6),108(94.6),80(22.2),65(17.1),51(20.0); and a trace amount of unreacted 4-chlorodiphenylether: $m/e$ 206(35),204(100),141 (80),77(70),51(45).

Run 2: 4-Chlorodiphenylether + Sodium

The procedure followed was identical to run 1 except that after the addition of ammonium chloride, water (100 mL) was added followed by 50% hydrochloric acid (200 mL). Standard work-up gave a brown liquid (3.46 g). Gc/ms results were similar to run 1 except that benzene ($m/e$ 78,77,52,51) was present in a small amount.

Run 3: 4-Chlorodiphenylether + Lithium

4-Chlorodiphenylether (3.43 g, 16.75 mmole) in ether (30 mL) was added to ammonia (150 mL). Lithium metal (0.24 g, 35.2 mmole) was added to give a yellow solution to which was immediately added ammonium chloride (1.88 g, 35.2 mmole). Water (250 mL) was slowly added and the products were isolated using ether. A brown liquid (1.37 g) was obtained from the ether extract which was shown by

gc/ms to be a mixture virtually identical to that obtained in run 2. The alkaline extract gave a brown liquid (0.47 g) which was shown by gc/ms to be composed only of phenol ($\underline{m/e}$ 94,66,65,39).

Run 4: 4-Chlorodiphenylether + Sodium/Ethanol

4-Chlorodiphenylether (3.07 g, 15 mmole) in ether (15 mL) and ethanol (1.45 g, 31.5 mmole) was added to ammonia (150 mL). Sodium metal (0.72 g, 31.5 mmole) was added over 15 minutes to give a yellow solution. Ammonium chloride (1.68 g, 31.5 mmole) was added, followed by water (450 mL). During the subsequent work-up, an aliquot of the ether extract was washed with 5% sodium hydroxide and this alkaline phase was combined with the original alkaline extract. In this way, 0.51 g from the ether phase was obtained as a yellow liquid and 0.46 g from the alkaline extract. Gc/ms indicated that benzene, phenol and diphenylether were present in the ether layer, plus traces of unreacted 4-chlorodiphenylether and an unknown material with $\underline{m/e}$ 214,184,183,131. Gc/ms of the alkaline phase indicated that only phenol was present. The relative percentages are 36% diphenylether and 64% phenol. The isolated amounts account for 94.5% reduction.

Run 5: 4-Chlorodiphenylether + Sodium/Ethanol

This run was identical to run 4 except that the standard work-up was employed, that is, the entire ether extract was extracted with 5% sodium hydroxide. This resulted in a mixture of benzene and 0.87 g diphenylether from the ether extract and 0.88 g phenol from the alkaline extract. This gives a relative percentage of 65% phenol and 35%

diphenylether.


Run 6: 4-Chlorodiphenylether + Sodium/Ethanol

4-Chlorodiphenylether (2.05 g. 0.01 mole) in ether (20 mL) and
ethanol (1.94 g, 0.042 mole) was added to ammonia (150 mL). Sodium
metal (0.97 g, 0.042 mole) was added over 5 minutes and the mixture
was stirred for 10 minutes, which gave a white solution. Ammonium
chloride (2.25 g, 0.042 mole) was added, followed by water (300 mL).
Standard work-up gave a yellow ethereal solution from the ether extract
and 0.92 g of a yellow liquid from the alkaline extract. The ether
extract contained only benzene (m/e 78,77,52,51,50,39) and the aqueous
extract contained only phenol (m/e 94,66,65,39); 0.92 g represents a
97.8% isolated yield of phenol.


Run 7: 4-Chlorodiphenylether + Potassium amide

4-Chlorodiphenylether (2.05 g, 0.01 mole) in ether (20 mL) was
added to a solution of potassium amide (0.01 mole) in ammonia (100 mL).
The mixture was stirred for 4 hours, then ammonium chloride (0.53 g,
0.01 mole) was added and the mixture was left overnight. Water (100 mL)
was added, the solution was acidified with hydrochloric acid, and was
worked up with ether. A brown liquid (1.84 g) was obtained; $^1$H nmr: $\delta$
6.8-7.4(m). Gc/ms revealed that only unreacted 4-chlorodiphenylether
was present; m/e 206(45.4),204(100.0),169(12.6),141(45.4),77(41.7),
51(14.1). The quantity 1.84 g accounts for a recovery of 89.8% of the
original starting material.

Run 8: 3-Chlorodiphenylether + Sodium/Ethanol

3-Chlorodiphenylether (2.05 g, 0.01 mole) in ether (20 mL) and
ethanol (1.93 g, 0.042 mole) was added to ammonia (100 mL). Sodium
metal (0.97 g, 0.042 mole) was added over 5 minutes and the mixture
was stirred for 10 minutes until discharge of the blue colour. Ammonium
chloride (2.25 g, 0.042 mole) was added, followed by water (300 mL).
Standard work-up gave 0.14 g from the ether extract and 0.69 g from
the alkaline extract. Gc/ms of the ether extract indicated the presence
of benzene ($\underline{m/e}$ 78,77,52,51,39) and an unresolved mixture of diphenyl-
ether, dihydro- and tetrahydrodiphenylethers; $\underline{m/e}$ 174(23.2),173(10.4),
172(13.7),170(26.9),142(11.8),141(15.9),96(23.3),95(27.0),91(21.2),
81(11.1),80(23.2),79(62.2),78(41.9),77(100.0),67(17.2),66(11.0),65(16.6),
53(16.5),52(13.0),51(43.5),50(11.5),41(18.1),39(33.9). Gc/ms of the
alkaline extract indicated that only phenol ($\underline{m/e}$ 95,94,66,65,39) was
present. The relative percentages were 90% phenol and 10% of the un-
resolved mixture.

Run 9: 3-Chlorodiphenylether + Sodium/Ethanol

3-Chlorodiphenylether (2.05 g, 0.01 mole) in ether (20 mL) and
ethanol (0.46 g, 0.01 mole) was added to ammonia (100 mL). Sodium
metal (0.23 g, 0.01 mole) was added, followed by ammonium chloride
(0.53 g, 0.01 mole) immediately after dissolution of the sodium. Water
(300 mL) was added and then the mixture was worked up in the standard
manner. The ether extract (1.44 g) consisted of benzene ($\underline{m/e}$ 78,77,52,
51,39), diphenylether ($\underline{m/e}$ 171,170,142,141,115,77,51) and 3-chloro-
diphenylether ($\underline{m/e}$ 206,204,269,141,77,51). Glc at 140°C indicated that

the mixture was 35.1% diphenylether and 64.9% 3-chlorodiphenylether
(as weight percentages).  The alkaline extract (0.21 g) contained only
phenol (m/e 94,66,65,39).  The relative yields were 22.8% phenol, 30.7%
diphenylether and 46.5% 3-chlorodiphenylether.


## Run 10: 3,4-Dichlorodiphenylether + Sodium

3,4-Dichlorodiphenylether (3.59 g, 15 mmole) in ether (30 mL) was
added to ammonia (150 mL).  Sodium metal (0.72 g, 31.5 mmole) was added
over 15 minutes to give a brown solution.  Ammonium chloride (1.68 g,
31.5 mmole) was then added, followed by water (450 mL).  Standard
work-up gave a brown liquid (1.97 g) from the ether extract and a brown
liquid (0.22 g) from the alkaline extract.  Gc/ms of the ether extract
indicated the presence of benzene (m/e 78,77,52,51,39); diphenylether:
 m/e 171(13.0),170(100.0),169(22.4),142(43.8),141(58.6),115(20.1),77(50.2),
65(13.0),51(55.7),39(27.4); and 3,4-dichlorodiphenylether: m/e 242(10.6),
240(64.0),239(16.8),238(100.0,M$^+$),177(17.3),175(54.7),168(26.9),139(22.7),
77(97.3),51(68.3).  Glc at 170°C indicated a mixture of 40.1% diphenyl-
ether and 59.9% 3,4-dichlorodiphenylether was present.  The alkaline
extract was composed only of phenol (m/e 94,66,65,39).  The relative
yields were 19.6% phenol, 38.9% diphenylether, and 41.4% 3,4-dichloro-
diphenylether.


## Run 11: 3,4-Dichlorodiphenylether + Sodium/Ethanol

The procedure followed was the same as for run 10 except that
ethanol (1.45 g, 31.5 mmole) was added along with the starting material.

Standard work-up gave 2.55 g of a brown liquid from the ether extract and 0.30 g of a brown liquid from the alkaline extract. The ether extract contained diphenylether and 3,4-dichlorodiphenylether. Glc at 170°C gave 40.4% diphenylether and 59.6% 3,4-dichlorodiphenylether. The alkaline extract contained only phenol. The relative percentages were 20.4% phenol, 38.8% diphenylether and 40.8% 3,4-dichlorodiphenyl-ether.

Run 12: 3,4-Dichlorodiphenylether + Sodium/Ethanol

3,4-Dichlorodiphenylether (2.39 g, 0.01 mole) in ether (20 mL) and ethanol (2.9 g, 0.063 mole) was added to ammonia (100 mL). Sodium metal (1.45 g, 0.063 mole) was added over 10 minutes and the mixture was stirred for 15 minutes to give a white solution. Ammonium chloride (3.37 g, 0.063 mole) was added, followed by water (300 mL). Standard work-up gave a yellow ethereal solution of benzene ($\underline{m/e}$ 78,77,52,51,39) from the ether extract, and 0.66 g of phenol ($\underline{m/e}$ 95,94,66,65,39) from the alkaline extract. The isolated yield of phenol was 70%.

Run 13: 3,4-Dichlorodiphenylether + Lithium/Ethanol

The procedure used was identical to run 12 except that lithium metal (0.44 g, 0.063 mole) replaced the sodium metal. Standard work-up gave 0.84 g of a yellow liquid from the ether extract and 0.63 g of a yellow liquid from the alkaline extract. The ether extract was composed of benzene ($\underline{m/e}$ 78,77,52,51,39) and an unresolved mixture of diphenylether and tetrahydrodiphenylether: $\underline{m/e}$ 174(16.0),170(16.3),

141(11.2),95(26.5),94(30.5),79(61.0),77(100.0). The alkaline extract
contained just phenol (m/e 94,66,65,39). The relative yields were 57.8%
phenol and 42.2% of the unresolved mixture.


Run 14: 3,4-Dichlorodiphenylether + Potassium amide

3,4-Dichlorodiphenylether (2.39 g, 0.01 mole) in ether (20 mL) was
added to a solution of potassium amide (0.01 mole) in ammonia (100 mL).
The mixture was stirred for 4 hours and then ammonium chloride (0.53 g,
0.01 mole) was added and the mixture was left overnight. Work-up with
ether gave a yellow liquid (2.11 g); $^1$H nmr: $\delta$ 6.8-7.5(m). Gc/ms
revealed that only unreacted 3,4-dichlorodiphenylether was present.
The quantity 2.11 g accounted for a recovery of 88.3% of the original
amount of starting material.


Run 15: 4-Chloro-4'-methyldiphenylether + Sodium/Ethanol

4-Chloro-4'-methyldiphenylether (2.19 g, 0.01 mole) in ether (30 mL)
and ethanol (0.97 g, 0.021 mole) was added to ammonia (100 mL). Sodium
metal (0.48 g, 0.021 mole) was added over 5 minutes, followed by addition
of ammonium chloride (1.12 g, 0.021 mole). Water (300 mL) was added
and the mixture was worked up in the usual manner. The ether extract
gave a yellow liquid (1.10 g), which was composed of benzene (m/e 78,
77,52,51,50,39); toluene: m/e 92(60.8),91(100.0),65(10.7),45(5.9),
39(6.8); and 4-methyldiphenylether: m/e 185(17.5),184(100.0,M$^+$),183
(15.2),155(8.5),141(9.2),91(69.4),77(12.5),65(8.3),51(6.3). After
further concentration, no benzene was present and only a very small

amount of toluene was present. The alkaline extract gave a yellow liquid (0.37 g); $^1$H nmr: $\delta$ 2.25(s),6.75-7.2(m). Gc/ms indicated a mixture of phenol ($\underline{m/e}$ 95,94,66,65,39) and 4-methylphenol: $\underline{m/e}$ 108 (100.0,$M^+$),107(82.7),92(27.0),91(39.0),90(13.1),77(57.4). Integration of the $^1$H nmr spectrum indicated a mixture of 23.4% phenol and 76.6% 4-methylphenol. The relative yields were 8.2% phenol, 26.9% 4-methyl-phenol and 64.9% 4-methyldiphenylether.

## Other Reactions

### Run 16: 4,5-Dichloroveratrole + Sodium/Ethanol

4,5-Dichloroveratrole (2.07 g, 0.01 mole) in ether (30 mL) and ethanol (0.97 g, 0.021 mole) was added to ammonia (100 mL). Sodium metal (0.48 g, 0.021 mole) was added over 5 minutes. Ammonium chloride (1.12 g, 0.021 mole) was then added and the mixture was left overnight. Water (100 mL) was added, the solution was acidified with hydrochloric acid, and was then extracted with ether. This afforded a yellow liquid (1.67 g). Gc/ms indicated the presence of veratrole: $\underline{m/e}$ 139(12.0), 138(100.0,$M^+$),123(54.3),95(65.7),80(12.6),77(56.1),65(28.9),52(32.7), 51(24.8); 4-chloroveratrole: $\underline{m/e}$ 174(33.2),172(100.0,$M^+$),157(61.2), 93(44.5),65(52.5),51(36.3); and unreacted 4,5-dichloroveratrole: $\underline{m/e}$ 210(10.0),208(62.1),206(100.0,$M^+$),193(38.6),191(61.1),163(27.7),128 (55.6),127(31.3),113(38.5),99(49.5). Comparison of the chromatogram intensities suggested that the major component was the unreacted starting material and there was only a small amount of 4-chloroveratrole

present.

Run 17: 4,5-Dichloroveratrole + Sodium/Ethanol

4,5-Dichloroveratrole (2.07 g, 0.01 mole) in ether (30 mL) and
ethanol (1.93 g, 0.042 mole) was added to ammonia (100 mL). Sodium
metal (0.97 g, 0.042 mole) was added over 10 minutes and the mixture
was stirred for 5 minutes untildischarge of the blue colour. Ammonium
chloride (2.25 g, 0.042 mole) was added and the mixture was left over-
night. Work-up as in run 16 gave a yellow liquid (1.25 g) which was
shown by gc/ms to be a mixture of anisole: $\underline{m/e}$ 108(100.0,$M^+$), 79(18.1),
78(70.8),77(22.8),65(59.7),45(36.0),39(32.5); and veratrole: $\underline{m/e}$
139(9.1),138(100.0),123(45.8),95(38.8),77(43.1),65(18.0),52(13.2),
51(10.3). The major component was veratrole and was present to the
extent of about 90% of the product mixture.

Run 18: 4-Chlorodiphenylether + 4-Chlorophenol + Sodium/Ethanol

A mixture of 4-chlorodiphenylether (2.05 g, 0.01 mole) and 4-chloro-
phenol (1.28 g, 0.01 mole) in ether (20 mL) and ethanol (0.97 g, 0.021
mole) was added to ammonia (100 mL). Sodium metal (0.48 g, 0.021 mole)
was added and, as soon as the blue colour disappeared, ammonium chloride
(1.12 g, 0.021 mole) was added. Water (300 mL) was added and the
mixture was worked up in the standard manner. The ether extract gave
a yellow liquid (1.41 g) which was composed of benzene ($\underline{m/e}$ 78,77,52,
51,39); diphenylether ($\underline{m/e}$ 171,170,169,141,115,77,51,50,39);and 4-chloro-
diphenylether ($\underline{m/e}$ 206,205,204,141,77). Glc at 140°C indicated a

composition of 71.5% diphenylether and 28.5% 4-chlorodiphenylether (as weight percentages). The alkaline extract (1.31 g) was a mixture of phenol (m/e 95,94,66,65,39); and 4-chlorophenol: m/e 130(33.6), 129(26.8),128(100.0,M⁺),64(65.5),39(52.3). Glc at 140°C indicated a composition of 35% phenol and 65% 4-chlorophenol (as mole percentages). The relative yields of compounds were 20.6% phenol, 38.2% 4-chlorophenol, 31.0% diphenylether, and 10.2% 4-chlorodiphenylether.


## Run 19: Dibenzo-1,4-dioxin + Sodium/Ethanol

Dibenzo-1,4-dioxin (0.85 g, 4.6 mmole) in ether (20 mL) and ethanol (0.45 g, 9.69 mmole) was added to ammonia (100 mL). Sodium metal (0.22 g, 9.69 mmole) was added over 2 minutes and the mixture was stirred for 15 minutes to give a red-brown solution. Ammonium chloride (0.52 g, 9.69 mmole) was added and the mixture was left overnight. Water (100 mL) was added and the solution was acidified with hydrochloric acid. Work-up with ether gave a brown solid (0.85 g), identified as 2-hydroxydiphenylether; m.p. 100-4°C (lit.,[47] 106-7°C); $^1$H nmr: δ 6.8-7.3(m); m/e 187(13.0),186(100.0,M⁺),185(18.6),184(74.3), 169(6.9),128(26.0),92(12.3),80(20.3),78(23.9),77(29.5),51(16.0); ν(max): 3400(br.),3050,1605,1590,1490,1350,1250,1100,880,815,780,750. The quantity 0.85 g accounts for a 98.9% isolated yield of 2-hydroxy-diphenylether.


## Run 20: Diphenylether + Sodium

Diphenylether (2.55 g, 15 mmole) in ether (15 mL) was added to

ammonia (150 mL). Sodium metal (0.72 g, 31.5 mmole) was added over 5 minutes and the mixture was stirred for 10 minutes to give a green solution. Ammonium chloride (1.68 g, 31.5 mmole) was added, followed by water (450 mL). Standard work-up gave a yellow liquid (0.08 g) from the ether extract; which was composed of benzene ($\underline{m/e}$ 78,77,52, 51,39); and diphenylether ($\underline{m/e}$ 170,169,142,141,94,77). The alkaline extract gave a yellow liquid (1.24 g) which contained only phenol ($\underline{m/e}$ 95,95,66,65,39). The relative percentages were 96% phenol and 4% diphenylether, with an isolated recovery of 91.3%.

### Run 21: Diphenylether + Lithium/Ethanol

Diphenylether (1.70 g, 0.01 mole) in ether (20 mL) and ethanol (0.97 g, 0.021 mole) was added to ammonia (100 mL). Lithium metal (0.15 g, 0.021 mole) was added over 5 minutes and the mixture was stirred for 5 minutes to give a white solution. Ammonium chloride (1.12 g, 0.021 mole) was added and the mixture was left overnight. Work-up with ether gave a yellow liquid (0.42 g) from the ether extract. Gc/ms indicated the presence of an unresolved mixture of diphenylether, a dihydrodiphenylether and a tetrahydrodiphenylether: $\underline{m/e}$ 174,172, 170,141,96,79,78,77. The approximate yield, using an average of 172 for the molecular weight, was 24.4%. The $^1$H nmr spectrum showed $\delta$ 2.9(2 overlapping singlets), 4.9(s),5.0(s),5.6(s),6.8-7.3(m). The alkaline extract gave phenol (0.46 g); $\underline{m/e}$ 94,66,65,39.

0.22 g of the ether extract were dissolved in ethanol (5 mL) and 50% hydrochloric acid (20 mL) was added. The mixture was heated for

15 minutes, cooled, and extracted with ether to give a yellow liquid (0.08 g). The material was unfortunately lost before any analysis could be done.

The complete reaction was repeated and gave an ether extract (0.29 g) which had identical properties (^{1}H nmr, gc/ms) with that previously obtained. 50% Hydrochloric acid (40 mL) was added and the mixture was refluxed for 15 minutes. Extraction with ether gave a yellow liquid (0.06 g); $\nu$(max): 3300(br.),2910,1650,1595,1500,1475,1225,750. Gc/ms indicated the presence of 2-cyclohexenone: m/e 96(21.7,$M^+$),68 (100.0),42(12.4),41(8.8),40(28.8),39(30.6); phenol (m/e 95,94,66,65, 39); and diphenylether (m/e 171,170,169,142,141,77,51,39). The 2-cyclohexenone and phenol peaks in the gc/ms were overlapping.


Run 22: 4-Methyldiphenylether + Sodium/Ethanol

4-Methyldiphenylether (1.84 g, 0.01 mole) in ether (20 mL) and ethanol (0.97 g, 0.021 mole) was added to ammonia (100 mL). Sodium metal (0.48 g, 0.021 mole) was added and the mixture was stirred for 5 minutes, after which ammonium chloride (1.12 g, 0.021 mole) was added. Water (300 mL) was added and the mixture was worked up in the standard manner. The ether extract gave a yellow liquid (0.14 g); ^{1}H nmr: $\delta$ 2.3(s),4.8(s),5.3(s),5.6(s),6.7-7.4(m). Gc/ms indicated that the extract contained benzene (m/e 78,77,52,51,50,39); toluene (m/e 92,91,65,63,51,39); and an unresolved mixture of 4-methyldiphenyl-ether and a dihydro-4-methyldiphenylether(s): m/e 186(68.0),184(28.0), 171(27.8),108(68.9),107(35.8),94(97.5),93(41.5),92(28.7),91(100.0),

79(33.7),78(21.2),77(74.3),65(21.2).  The alkaline extract gave an
orange liquid (1.02 g); $^1$H nmr: $\delta$ 2.2(s),6.25(s,br.-removed by $D_2O$),
6.6-7.1(m).  Gc/ms indicated the presence of phenol (m/e 94,66,65,39);
and 4-methylphenol: m/e 108(81.2),107(100.0),79(20.6),77(27.3),51(9.0).
Integration of the $^1$H nmr spectrum indicated a relative mixture of
39.6% phenol and 60.4% 4-methylphenol.  The total relative yields
were 36.2% phenol, 55.3% 4-methylphenol and 8.5% of the unresolved
mixture.


Run 23: Veratrole + Sodium/Ethanol

Veratrole (1.38 g, 0.01 mole) in ether (20 mL) and ethanol (0.97 g,
0.021 mole) was added to ammonia (100 mL).  Sodium metal (0.48 g, 0.021
mole) was added and the blue solution was stirred for 15 minutes.
Ammonium chloride (1.12 g, 0.021 mole) was then added and the mixture
was left overnight.  Water (100 mL) was added, the solution was
acidified and extracted with ether to give an orange liquid (0.88 g);
$^1$H nmr: $\delta$ 3.7(s),5.7(s,br.-removed by $D_2O$),6.75(s).  Gc/ms indicated the
presence of a mixture of anisole: m/e 108(100.0),77(68.5),65(57.2),39
(71.6); guaiacol: m/e 125(13.2),124(96.3,$M^+$),110(11.4),109(100.0),81
(60.6),53(23.0),39(13.6); and veratrole: m/e 139(15.4),138(100.0),
123(68.8),95(66.9),77(52.0),65(24.3),52(21.6),51(15.0),41(18.8).  The
major component was veratrole, while anisole was obtained in only a
very small yield.

Run 24: 4-Chlorophenol + Sodium

4-Chlorophenol (1.93 g, 15 mmole) in ether (15 mL) was added to ammonia (150 mL). Sodium metal (0.72 g, 31.5 mmole) was added which gave a white solution. Ammonium chloride (1.68 g, 31.5 mmole) was added, followed by water (450 mL). Standard work-up gave 0.87 g (61.7%) of phenol ($\underline{m/e}$ 94,66,65,39); and a trace amount of 4-chlorophenol ($\underline{m/e}$ 130,128,65).

In a similar run using more care during the work-up, a 97% crude yield of phenol was obtained. The material solidified on standing and was recrystallized from ligroin (b.p. 35-60°C) to give phenol as white spars; m.p. 38.5-40°C (lit.,[84] 43°C); $\gamma$(max): 3300(br.),1600, 1500,1475,1370,1230,810,750,690. A trace amount of unreacted 4-chlorophenol was present as well.

Run 25: Sodium 4-chlorophenate + Sodium/Ethanol

4-Chlorophenol(1.93 g, 15 mmole) was added to a solution of sodium hydroxide (0.6 g, 15 mmole) in methanol (20 mL) and the mixture was refluxed for 15 minutes. Benzene was added and the solution was concentrated to give a clear oil which was added to ammonia (150 mL) with the aid of ethanol (10 mL). Sodium metal (0.72 g, 31.5 mmole) was added and the mixture was stirred for 15 minutes to give a white solution. Ammonium chloride (1.68 g, 31.5 mmole) was added, followed by water (450 mL). Standard work-up gave 1.26 g of a liquid which solidified on standing. Gc/ms indicated that phenol ($\underline{m/e}$ 95,94,66,65, 39) was the only product obtained. The quantity 1.26 g gives an isolated

yield of 89.4%.

Run 26: 4-Chlorophenol + Potassium amide + Sodium

4-Chlorophenol (1.93 g, 15 mmole) in ether (15 mL) was added to
a solution of potassium amide (15 mmole) in ammonia (150 mL) and the
mixture was stirred for 5 minutes. Sodium metal (0.72 g, 31.5 mmole)
was then added and the mixture was stirred for 15 minutes to give a
brown solution. Ammonium chloride (2.49 g, 46.5 mmole) was added,
followed by water (450 mL). Work-up with ether of the acidified
mixture gave 1.31 g (92.7%) of phenol (m/e 95,94,66,65,39); plus a
trace amount of 4-chlorophenol (m/e 130,128,65,64).

Run 27: 4-Methylphenol + Sodium

4-Methylphenol (1.62 g, 15 mmole) in ether (15 mL) was added to
ammonia (150 mL). Sodium metal (0.72 g, 31.5 mmole) was added to give
a blue solution which was stirred for 10 minutes. Ammonium chloride
(1.68 g, 31.5 mmole) was added, followed by water (450 mL). Work-up
of the acidified solution with ether gave 1.54 g (94.9%) of unreacted
4-methylphenol; [1]Hnmr: $\delta$ 2.2(3H,s),6.7-7.1(4H.m); m/e 108(84.3),107
(100.0),79(18.7),77(23.2),53(9.3),51(9.4),39(9.5).

Run 28: 4-Chloro-3,5-dimethylphenol + Sodium/Ethanol

4-Chloro-3,5-dimethylphenol (1.57 g, 0.01 mole) in ether (20 mL)
and ethanol (0.97 g, 0.021 mole) was added to ammonia (100 mL).
Sodium metal (0.48 g, 0.021 mole) was added over 5 minutes and the
mixture was stirred for 15 minutes to give a white solution. Ammonium

chloride (1.12 g, 0.021 mole) was added, followed by water (300 mL).
Work-up with ether of the acidified solution gave a brown liquid (1.18 g)
which solidified on standing; $^1$H nmr: $\delta$ 2.2(6H,s),6.5(3H.m); $\nu$(max):
3200(br.),1620,1595,1340,1150,1025,945,830. Gc/ms indicated that this
material was 3,5-dimethylphenol: m/e 123 (8.9),122(99.8,M$^+$),121(38.8),
108(8.7),107(100.0),105(10.6),91(19.4),79(23.6),78(9.6),77(37.5),65(9.2),
53(12.1),51(15.0),39(20.4); plus a very small amount of unreacted
4-chloro-3,5-dimethylphenol: m/e 158(52.8),156(60.6,M$^+$),122(49.0),
121(100.0).  The quantity 1.18 g gave a 96.6% yield of 3,5-dimethyl-
phenol.

# References

1. H. Buser, Chemosphere 8, 415 (1979).

2. J.A. Moore, Science 203, 741 (1979).

3. L. Hodges, "Environmental Pollution" (Toronto, Holt, Rinehart and Wilson, Inc., 1973), p. 200.

4. S.I. Varshauskaya and N.N. Melnikov, Deposited Doc. SPSTL 6 Khp-D-80 (1980); Chem. Abs. 96, 99249 (1982).

5. F. Bayer, Fr. Patent 1,576,298 (1969); Chem. Abs. 72, 77667 (1970)

6. D.E. Willis, M.E. Zinck and R.F. Addison, Chemosphere 7, 787 (1978).

7. T. Cairns, L. Fishbein and R.K. Mitchum, Biomed. Mass. Spec. 7, 484 (1980).

8. H. Buser, C. Rappe and H. Bosshardt, Chemosphere 5, 431 (1978).

9. A. Hay, Nature 262, 636 (1976).

10. F. Karasek and F.I. Onuska, Anal. Chem. 54, 309A (1982).

11. C. Botré, A. Memoli and F. Alhaique, Environ. Sci. Tech. 12, 335 (1978).

12. E. Lahaniatia, Inst. Oekol. Chem. Kolloq 599, 34 (1980); Chem. Abs. 95, 115740 (1981).

13. E. Jansson, G. Sundsström and B. Ahling, Sci. Tot. Environ. 10, 209 (1978).

14. G.W. Gribble, Chemistry 47, 15 (1974).

15. D. Kriebel, Environment 23, 6 (1981).

16. N.J. Bunce, Y. Kumar and B.G. Brownlee, Chemosphere 7, 155 (1978).

17. D.G. Crosby and A.J. Wong, Chemosphere 5, 327 (1976).

18. A. Norström, K. Andersson and C. Rappe, Chemosphere 6, 241 (1977).

19. K.H. Sweeny, AI. Ch. E. Symp. Ser. 77, 72 (1981); Chem. Abs. 92, 57210 (1982).

20. D.L. Norman, U.S. Patent Appl. 180,752 (1980); Chem. Abs. 96, 168161 (1982).

21. L.L. Pytlewski, K. Krevitz and A.B. Smith, U.S. Patent Appl. 142,865 (1980); Chem. Abs. 96, 19800 (1982).

22. J.M. Harrison and R.G. Wilkonson, Brit. Patent Appl. 79/36,764 (1979); Chem. Abs. 95, 85851 (1981).

23. A. Oku, K. Yasufuku and H. Kataoka, Chem. and Ind., 841 (1978).

24. J.G. Smith and G.L. Bubbar, J. Chem. Tech. Biotechnol. 30, 620 (1980).

25. N.L. Holly, Chem. Rev. 74, 243 (1974).

26. T.C. Cheng, L. Headley and A.F. Halasa, J. Amer. Chem. Soc. 93, 1502 (1971).

27. K. Tsujimoto, s. Tasaka and M. Ohashi, J. Chem. Soc. C, 758 (1975).

28. J.A. Barltrop and D. Bradbury, J. Amer. Chem. Soc. 95, 5085 (1973).

29. M.Th.M. Tulp and O. Hutzinger, Chemosphere 7, 761 (1978).

30. C.B. Wooster and K.L. Godfrey, J. Amer. Chem. Soc. 59, 596 (1937).

31. A.J. Birch and G. Subba Rao, Adv. Org. Chem. 8, 1 (1972).

32. A.J. Birch, J. Roy. Inst. Chem. 81, 100 (1957).

33. A.J. Birch, Quart. Rev. 4, 69 (1950).

34. A.J. Birch, Quart. Rev. 12, 17 (1958).

35. P. Rabideau and E. Burkholder, J. Org. Chem. 43, 4283 (1978).

36. A.J. Birch, D. Nasipuri and H. Smith, Experientia 15, 126 (1959).

37. A.J. Birch, P. Hextall and S. Sternhell, Austral. J. Chem. 7, 256 (1954).

38. H. Smith, in "Reduction" (ed. R.L. Augustine) (New York, Marcell. Dekker, Inc., 1968) Ch. 2.

39. G.F. White, J. Amer. Chem. Soc. 45, 779 (1923).

40. F.M. Hudson, Diss. Abs. 25, 99 (1964); Chem. Abs. 61, 13143 (1964).

41. C.A. Kraus and G.F. White, J. Amer. Chem. Soc. 45, 768 (1923).

42. J. Weiss and F.C. Schmidt, Bol. Col. Quim. Puerto Rico 13, 15 (1956); Chem. Abs. 51, 12860g (1957).

43. A.J. Birch, J. Chem. Soc., 593 (1946).

44. P. Sartoretto and F. Sowa, J. Amer. Chem. Soc. 59, 603 (1937).

45. D. Eargle, J. Org. Chem. 28, 1703 (1963).

46. M. Curcumelli-Rodostamo and M. Kulka, in "Alkaloids" vol. 4 (ed. R.H.F. Manske) (New York, Acedimic Press, 1967).

47. M. Tomita, Y. Inubushi and H. Niwa, J. Pharm. Soc. Japan 72, 206 (1952); Chem. Abs. 47, 6428f (1953).

48. Y. Inubushi and K. Nomura, Yakugaku Zasshi 82, 1341 (1962); Chem. Abs. 59, 605e (1963).

49. H. Gilman and J. Dietrich, J. Org. Chem. 22, 851 (1957).

50. R.L. Huang, J. Chem. Soc., 3084 (1954).

51. R.L. Huang, J. Chem. Soc., 3088 (1954).

52. W. Langham, R.Q. Brewster and H. Gilman, J. Amer. Chem. Soc. 63, 545 (1941).

53. J.A. Sperry, U.S. Dept. Com., Office Tech. Serv. PB Rept. 145,953 (1959); Chem. Abs. 58, 4592d (1963).

54. G.G. Choudhry, G. Sundström, L.O. Ruzo and O. Hutzinger, J. Agric. Food Chem. 25, 1371 (1977).

55. S.R. Cater, B.Sc.(Hons.) Thesis, Brock University (1980).

56. M.H. Mach and J.F. Bunnett, J. Org. Chem. 45, 4660 (1980).

57. C.A.M. McCullough, Summer Research Student, Brock University (1980).

58. F. Ullmann and P. Sponagel, Ber. 38, 2211 (1905).

59. P.E. Fanta, Chem. Revs. 64, 613 (1964).

60. H. Weingarten, J. Org. Chem. 29, 3624 (1964).

61. R.G.R. Bacon and O.J. Stewart, J. Chem. Soc., 4953 (1965).

62. H. Weingarten, J. Org. Chem. 29, 977 (1964).

63. P.E. Fanta, Synthesis, 9 (1974).

64. A. Gara, K. Andersson, C. Nilsson and A. Norström, Chemosphere 10, 365 (1981).

65. F.M. Beringer, M. Drexler, E.M. Gindler and C.C. Lumpkin, J. Amer. Chem. Soc. 75, 2705 (1953).

66. J.R. Crowder, E.E. Glover, M.F. Grundon and H.X. Kaempfon, J. Chem. Soc., 4578 (1963).

67. F.M. Beringer, R.A. Fak, M. Karniol, I. Lillien, G. Masullo, M. Mausner and E. Sommer, J. Amer. Chem. Soc. 81, 342 (1959).

68. J. Bruce and F. Sutcliffe, J. Chem. Soc., 3820 (1956).

69. M. Tomita, T. Nakano and K. Hirai, J. Pharm. Soc. Japan 74, 934 (1954); Chem. Abs. 49, 10964a (1955).

70. H.C. Brown and S. Krishnamurthy, J. Org. Chem. 34, 3918 (1969).

71. A.P. Krapcho and A.A. Bothner-By, J. Amer. Chem. Soc. 81, 3658 (1959).

72. J.F. Bunnett and G. Scorrano, J. Amer. Chem. Soc. 93, 1190 (1971).

73. J.F. Bunnett and C.E. Moyer, J. Amer. Chem. Soc. 93, 1183 (1971).

74. F.A. Carey and R.J. Sundberg, "Advanced Organic Chemistry" Part B (New York, Plenum Press, 1980), p. 282-284.

75. J.A. Marshall and J.J. Partridge, Tetrahedron 25, 2159 (1969).

76. E.J. Corey and M. Chaykousky, J. Amer. Chem. Soc. 87, 1353 (1965).

77. H.O. House, "Modern Synthetic Reactions" 2nd ed. (Don Mills, W.A. Benjamin, Inc., 1972), p. 198.

78. Y. Inubushi and K. Nomura, Yakugaku Zasshi 82, 696 (1962); Chem. Abs. 58, 4545h (1963).

79. a) A.I. Vogel, "A Textbook of Practical Organic Chemistry", 3rd ed. (London, Longmans, Green and Co. Ltd., 1967), p. 163-178.

   b) A.J. Gordon and R.A. Ford, "The Chemist's Companion", (Toronto, John Wiley and Sons, Inc., 1972), p. 430-436.

80. A.I. Vogel, "A Textbook of Practical Organic Chemistry", 3rd ed. (London, Longmans, Green and Co. Ltd., 1967), p. 192-193.

81. C.M. Suter and F.O. Green, J. Amer. Chem. Soc. 59, 2578 (1937).

82. R.Q. Brewster and G. Stevenson, J. Amer. Chem. Soc. 62, 3144 (1940).

83. H. Gilman and J. Dietrich, J. Amer. Chem. Soc. 79, 1439 (1957).

84. R.C. Weast, ed. "Handbook of Chemistry and Physics", (Cleveland, CRC Press, Inc., 1975) 56th ed., p. C-421.