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**UNSYMMETRICAL ORGANOBI SMUTH COMPOUNDS**

by

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for the Degree of****DOCTOR OF PHILOSOPHY****Major Subject                  Organic Chemistry****Approved:**

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## INTRODUCTION

The synthesis of triethylbismuth in 1850 by Lbwig and Schweizer(76) inaugurated the study of the chemistry of organobismuth compounds. The spontaneous inflammability of these trialkyl derivatives limited investigation in the field until Michaelis and Follis(84) prepared triphenylbismuth in 1887. These aromatic compounds were stable in air and could be converted to pentavalent alhalides which possessed unusual stability. In 1913, Challenger reported the beginning of an investigation on the preparation and resolution of optically active organobismuth compounds. In the years which followed, up until 1934, he and his co-workers (13-27, 118), although they did not accomplish their original purpose, did make contributions of paramount importance in the field of organobismuth compounds.

The effectiveness of triphenylbismuth, used as a salve, in the treatment of canine syphilis was reported by Glemesa (39, 40, 41) in 1923. Two years later, Supniewski and Adams (111) and Supniewski(109, 110) prepared a number of water-soluble organobismuth compounds for possible therapeutic utilization. Bismuth therapy in the past had been based entirely upon the use of colloidal bismuth, inorganic bismuth salts, or bismuth salts of organic acids. With these, in general, absorption by body fluids was slow and toxicity high.

The use of water-soluble organobismuth compounds offers new opportunities for investigation into bismuth therapy, but the preparation of these compounds presents many difficulties. In these laboratories the fundamental problem has been to prepare such compounds. Of the many reactions attempted, the synthesis of organobismuth compounds in liquid ammonia(51) and through the arylidiazonium chloride-bismuth chloride complexes(52) held most promise. The development of these reactions presents unusual problems in laboratory technique. They will be discussed in another section of this thesis.

## PART I. THE CHEMISTRY OF ORGANOBIISMUTH COMPOUNDS

### Introduction

A study of the relative reactivities of organometallic compounds would indicate that reactivity, in part, is dependent upon the strength of the carbon-metal bond in the organometallic molecule. Thus, the organoalkali compounds which possess a weak and highly polar bond, represent a highly reactive type. Hein and co-workers(65) have found these compounds to be highly polar in character and able to conduct an electric current when dissolved in the proper medium. The strength of the carbon-metal bond, and consequently reactivity, may be correlated also with the metallic nature of the central atom of the organometallic molecule, since with enhanced metallicity, the bond becomes increasingly weaker. It has been predicted therefore, on the basis of these generalizations, that Element 87 will form the most reactive organometallic compounds known.

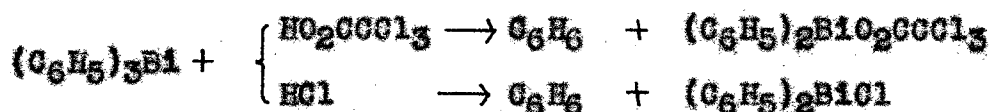
In their thorough investigation of the triphenyl compounds of the elements of the B-family of Group V, Smith and Andrews(106) have observed a definite increase in molal heat capacity with increasing atomic weight of the central atom. They have proposed, as an explanation of this, the greater atomic volume of the element, which would give the R groups attached to it greater freedom of motion and hence less

stability. Although such an explanation agrees admirably with other evidence for reactivity in any single family of the elements of the A-families of Groups I, II, and III, and the B-families of Groups IV, V, VI, and VII, it cannot explain the decreasing reactivity with increasing atomic weight in the B-families of Groups I, II, and III, and the A-families of Groups IV, V, VI, and VII. It should be noted, furthermore, that their data, numerically, give little indication of the difference in stability and reactivity between two adjacent members of a family, e.g., antimony and bismuth.

Gilman and Jones(45) have found that the relative reactivities of many RM compounds parallel and may be related directly to the ionization potentials of the corresponding metallic atoms. In a given group or sub-group, the lower the ionization potential of the metal the more reactive will be its simple organometallic compound. There appear to be some exceptions, but by and large, this generalization holds true. The ionization potentials for bismuth and antimony are not known with certainty, but are given as 8 and 9 volts, respectively. This difference of approximately one volt is large when it is seen that the difference between the potentials of lithium and cesium is only 1.49 volts. Thus the ionization potentials of the corresponding gaseous metallic atoms would indicate marked distinctions between the properties and reactivity of organoantimony and organobismuth compounds, and this is

actually the case. The carbon-antimony linkage is extremely stable, whereas the weakness of the carbon-bismuth bond is the most characteristic property of organobismuth compounds.

Organobismuth compounds resemble organomercury, organolead, and organotin compounds in reactivity. Cleavage reactions with hydrogen chloride and trichloroacetic acid.



would indicate that tetraphenyllead and diphenylmercury are more reactive than triphenylbismuth and that tetraphenyltin is extremely unreactive(12). Cleavage with formic and acetic acids, however, would give triphenylbismuth a greater reactivity than diphenylmercury or tetraphenyllead(71). Again, diphenylmercury and bismuth bromide yield triphenylbismuth in quantitative yields(18) whereas trivalent or quinquivalent aromatic bismuth compounds and mercuric chloride cannot form  $\text{R}_2\text{Hg}$  compounds(77). Thus, organomercury compounds might be considered more reactive than organobismuth compounds since the preparation of a lesser reactive organometallic compound is accomplished, in general, by the reaction between a more reactive organometallic compound and a metal halide. The reaction between diphenylmercury and bismuth bromide is not a reaction of general application, however, since di-p-tolylmercury, di-p-bromophenylmercury, di-p-carboethoxyphenylmercury, or di-p-carboethoxyphenylmercury and bismuth bromide do not yield organobismuth compounds(56). A similar behavior had

been noted also by Michaelis and Reese(85, 86) and Hausenbatter(64) in the reaction between diphenylmercury and antimony chloride. The former authors could not obtain organo-antimony compounds by the fusion of diphenylmercury and antimony chloride alone, or in the presence of solvents, whereas the latter obtained traces of triphenylantimony dichloride and diphenylantimony trichloride from the same reactants in dry xylene at 150° in a sealed tube.

Hilpert and Gröttner(67) have reported that diphenylmercury and bismuth metal at 250° in a stream of hydrogen gave a 41% yield of triphenylbismuth while triphenylbismuth and mercury under the same conditions gave but a 24% yield of diphenylmercury. The yield of triphenylbismuth in the first experiment may have been higher since organobismuth compounds are cleaved by hydrogen(68). The bismuth compound was not isolated but the residue remaining from the xylene extraction of the reaction mixture was analyzed for bismuth. On this basis organobismuth compounds might be considered more reactive than organomercury compounds. It has not been possible to extend this reaction since di-*p*-tolylmercury and bismuth metal at 235° yield only free mercury and toluene. Both di-*p*-tolylmercury and tri-*p*-tolylbismuth are pyrolyzed even at the boiling point of *p*-cymene. No pyrolysis occurs in benzene or xylene but at these temperatures di-*p*-tolylmercury and bismuth metal do not react. With mercury, neither tri-*p*-tolylbismuth or tri-

phenylbismuth yield organomercury compounds when refluxed in benzene(55) but under the same conditions triphenylthallium, diphenylcadmium, and tetraphenyllead react with mercury to form diphenylmercury(45). On the basis of cleavage reactions with n-butylmercaptan and selenophenol, Nelson(47, 89) has shown organomercury compounds to be less reactive than both organobismuth and organolead compounds. Further complications are introduced by cleavage reactions with thiophenol which indicate the order,  $\text{Hg} > \text{Bi} > \text{Pb} > \text{Sn}$  (55).

As Nelson has pointed out, the reactivity of organolead, organobismuth, and organomercury compounds toward the -SH and -SeH groups is anomalous since these compounds are cleaved more readily by thiols and selenols than by more acidic carboxylic acids. He has suggested that a reactivity series based on cleavage by acidic hydrogens exclude these hydrogens of the selenol and thiol types. It is probable, too, that the tellurols would show the same anomalous behavior.

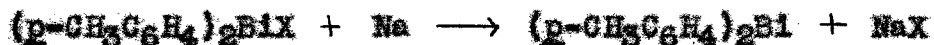
Based upon cleavage reactions with the carboxylic acids, he has proposed the following order of reactivity,  $\text{Pb} > \text{Hg} > \text{Bi} > \text{Sn}$ , and for cleavage by -SH and -SeH compounds,  $\text{Bi} > \text{Pb} > \text{Hg} > \text{Sn}$ . It is probable that his first series is the more accurate one although it is the reverse of the Keten series,  $\text{Bi} > \text{Hg} > \text{Pb}$ , which is based on cleavage by carboxylic acids, also.

It is very apparent, because of this conflicting data, that the term "relative reactivities" when applied to a series of organometallic compounds must be based on true equilibrium

reactions which have been allowed to come to equilibrium. This is very difficult with organometallic compounds where solubility, solvent, instability, and diverse unknown factors seriously limit the number of suitable reactions. Of the reactions described above only one appears to have a real significance. Hilpert and Griffner(67) made an attempt to approach the true equilibrium between triphenylbismuth and mercury and diphenylmercury and bismuth. In the other reactions all that has been measured is the rate at which a reaction is proceeding.

Although compounds containing  $\text{As-As-}$  and  $\text{Sb-Sb-}$  groups have been prepared, Paneth and Lohelt(93) mention only the possible formation of bisdimethylbismuth,  $(\text{CH}_3)_2\text{Bi-Bi}(\text{CH}_3)_2$ , and bisdiethylbismuth,  $(\text{C}_2\text{H}_5)_2\text{Bi-Bi}(\text{C}_2\text{H}_5)_2$ . In the reactions between heated bismuth mirrors and free methyl and ethyl radicals. The dimethylbismuth reported by Denham(32) may have been bisdimethylbismuth. Gnanasini and Santi(38) have prepared this compound or its oxide,  $(\text{CH}_3)_2\text{Bi-O-Bi}(\text{CH}_3)_2$ , by the reaction between sodium acetate and bismuth oxide. Bloke, Oakdale, and Smith(7) and Rosenblumowa and Well(100) were unable to prepare bisdiphenylbismuth by treating diphenylbismuth halides with various reducing agents. Gilman and Yablunsky(51) have reported recently the probable formation of the diarylbismuth radical in liquid ammonia. For example, di-*p*-tolylbismuth halide and one atom of sodium yield an intensely green colored

solution.



The addition of a second atom of the metal replaces the green color with the dark red which is characteristic of diarylbismuth sodium compounds.



The first reaction has been used to prepare a variety of free radicals in liquid ammonia(44).

Compounds containing -As-As- and -Sb-Sb- groups are known but the corresponding bismuth compounds have never been prepared. Bismuth compounds with mixed metal-metal bonds, e.g., -Bi-As-, are unstable and easily oxidized by air and decomposed by boiling water(35). Triphenylbismuth dichloride and copper bronze do not yield  $(\text{C}_6\text{H}_5)_3\text{Bi-Bi}(\text{C}_6\text{H}_5)_3$  even though pentavalent bismuth compounds possess unusual stability(19). Phenylbismuth dibromide and copper bronze yield only triphenylbismuth(18).

No bismuth compounds analagous to the aromatic arsenic and stibonic acids,  $\text{RAsO}(\text{OH})_2$  and  $\text{RSbO}(\text{OH})_2$ , have been prepared. Actually  $\text{H}_3\text{BiO}_3$  is a moderately strong base and basic bismuth salts of these acids have been made and investigated as spirocheticidal and treponemicidal agents. Lecoq(74) has reported the preparation of phenylbismuth oxide,  $\text{C}_6\text{H}_5\text{BiO}$ , which because of its unusual solubility may hydrate to a pentavalent form, but this is questionable. Triarylbiomuth dihydroxides,  $\text{R}_3\text{Bi}(\text{OH})_2$ , have been prepared(22, 55) and are easily soluble

in water.



The pH of such a solution is approximately 7.2 and after removal of the silver chloride by centrifuging the solution may be used therapeutically(55). The aqueous solution undergoes gradual decomposition, particularly in the presence of light. By evaporation of the aqueous solution the dihydroxide may be obtained as a pale yellow powder which does not redissolve in water but does so readily in 95% ethanol. Ethanolic solutions also undergo decomposition, yielding acetaldehyde and bismuth hydroxide.

Primary and secondary arsines,  $RAeH_2$  and  $R_2AsH$ , where R is aliphatic or aromatic, are known but the corresponding antimony or bismuth compounds have never been prepared.

Tertiary aromatic and aliphatic arsenic compounds and tertiary alkyl- and some mixed alkylarylantimony compounds add alkyl halides to form "onium" compounds. Tertiary bismuth compounds, both aliphatic and aromatic, do not add alkyl halides even at elevated temperatures. Generally, a secondary cleavage reaction takes place.



The reaction between triphenylbismuth dihalide and methylmagnesium iodide might have yielded a bismuthonium compound.



The products, instead, were triphenylbismuth, diphenylbismuth

bromide, phenylbismuth dibromide and bromobenzene(14). It cannot be assumed that methyltriphenylbismuthonium bromide formed as an intermediate and decomposed in a manner similar to that which takes place when trimethylphenylarsonium iodide is heated(119),



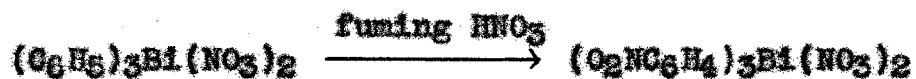
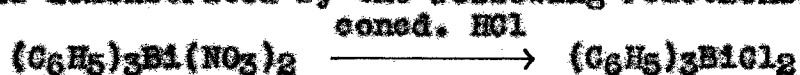
since no onium compound was formed when triphenylarsenic dihalide was treated with methylmagnesium iodide. There occurred instead reduction to triphenylarsenic.

The most stable valence in organobismuth compounds is 5. This valence is not demonstrated by the trialkylbismuth compounds although it has been proposed that quinquivalent derivatives are formed as intermediates and decompose spontaneously (80). The pentavalent aromatic bismuth compounds are comparatively stable. The various derivatives with halogens and pseudohalogens show a regular decrease in stability, the difluoride being the most stable. Based upon decomposition temperatures, these derivatives, in order of decreasing stability are: difluoride, dichloride, dicyanate, dibromide, diazide, and diiodide. The dithiocyanate and diselenocyanate have not been prepared.

Birchenbach and Kellerman(6) obtained a series of halogens and pseudohalogens by determining the decomposition potentials of the potassium salts in aqueous solution. This series,

F, CNO, OCN, Cl, N<sub>3</sub>, Br, CN, SCN, I, SeCN, TeCN, agrees well with the series described above.

Trivalent bismuth compounds are cleaved quantitatively by inorganic acids. In contrast the pentavalent compounds are but little affected by fuming nitric, boiling hydrochloric, or sulfuric acids, except for nuclear substitution. This stability is demonstrated by the following reactions.



## General Methods for the Preparation of Tertiary Bismuth

### Compounds

Organobismuth compounds are best prepared by interaction of a Grignard reagent and bismuth chloride. The yields range from 60 to 80% with most aromatic bismuth compounds and Gilman and Nelson(47) have reported the preparation of triethylbismuth in 88% yield. Bismuth cannot be introduced into the aromatic nucleus by means of the Bart reaction(3) or its modifications. Gilman and Swigoon(48) and Gilman and Yablunsky(52) have prepared organobismuth compounds by the copper bronze decomposition of aryl diazenium chloride-bismuth chloride complexes.

Tertiary bismuth compounds have been prepared by the following methods:

(a). Reaction of a Bismuth-Sodium or Bismuth-Potassium Alloy with an Alkyl or Aryl Halide. Ibwig and Schweitzer (76) prepared triethylbismuth by this method in 1850.

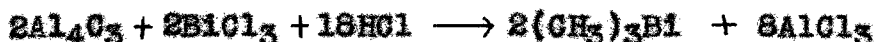
This was the first organobismuth compound reported in the literature. The reaction may be represented as follows:



Breed(8) and Dunhaupt(34) also prepared triethylbismuth, using a bismuth-potassium alloy. Michaelis and Polls(84), Michaelis and Marguardt(85), and Gilmeister(43) prepared aromatic bismuth compounds by means of a bismuth-sodium alloy and an aryl halide. Rosenblumowna and Well(100)

have reported more recently a modification of the Gillmeister method which gave improved yields. Details of this report are not available. Stilp(108) has prepared triphenylbismuth in 75% yield by the Michaelis method.

(b). Reaction Between Aluminum Carbide and Bismuth Chloride in Hydrochloric Acid. Hilpert and Ditmar(66) prepared trimethylbismuth by the slow addition of aluminum carbide to bismuth chloride in 20% hydrochloric acid solution.



It is apparent that this reaction is limited to the preparation of the trimethyl compound and that the yield would be affected by acid cleavage.

(c). Reaction of a Dialkylzinc Compound and a Bismuth Halide. Marquardt(80, 81) prepared trialkylbismuth compounds by the addition of an ether solution of a bismuth halide to a similar solution of a dialkylzinc compound. The difficulty in handling the spontaneously inflammable alkylzinc compound has made it necessary to replace this method by the equally effective but more easily handled Grignard reagent.

(d). Reaction of the Grignard Reagent and a Bismuth Halide. Pfeiffer and Pietsch(97) were the first to prepare organobismuth compounds by means of the Grignard reagent. This method was later employed by Stilp(108), Challenger and co-workers(14, 15, 18, 23), Worrall(120), Supniewski and Adams(111), Supniewski(109, 110), Classen and Ney(29),

Krause and Renwanz(72), Blicke, Oakdale and Smith(7), Davies, Norvick and Jones(31), Gilman and Nelson(47), Gräfftner and co-workers(62, 63), Pr. Fabrykant(37), Zhitkova and co-workers(121), Gilman, Yablunsky and Svigoon(54) and Gilman and Yablunsky(53). With phenyllithium and bismuth bromide, the yield of triphenylbismuth is 44%(121) and this method is, therefore, inferior to the Grignard method which gives yields of about 80%. It should be noted that regardless of the quantity of bismuth halide used, except when it exceeds the quantity demanded by the equation:  $3RMgX + BiX_3 \rightarrow R_3Bi + 3MgX_2$ , the tertiary compound is formed. The reaction can be used to prepare  $RBiX_2$  and  $R_2BiX$  compounds but not in good yields(63, 74, 114).

(f). Reaction Between Diphenylmercury and Bismuth Metal.

Hilpert and Gräfftner(67) have reported a 41% yield of triphenylbismuth when bismuth metal and diphenylmercury are heated at  $250^\circ$ . Frankland and Duppa(36) prepared triethylbismuth by heating diethylmercury and powdered bismuth at  $100-130^\circ$ . Tetraethyllead and powdered bismuth do not react after five hours heating at  $100-130^\circ$ . Tetraethyllead and bismuth chloride yield a mixture of ethylbismuth chlorides and probably some triethylbismuth(50). Phenylmercuric chloride and bismuth-sodium alloy yield traces of triphenylbismuth(121).

(g). Reaction Between Bismuth Electrodes and a Gaseous Hydrocarbon Under the Influence of an Electrical Discharge.

Trimethylbismuth is formed by an electrical discharge between two bismuth electrodes if a stream of methane is passed between the electrodes simultaneously with the electrical discharge(92).

(h). Reaction Between Free Radicals and Bismuth Mirrors.

Paneth and Hofeditz(92), Paneth(94), and Rice and co-workers(98) have reported that free methyl and ethyl radicals dissolve bismuth mirrors. Paneth and Lohleit(93) have obtained trialkylbismuth compounds with cold mirrors and methyl and ethyl radicals and with heated mirrors, in addition bisdimethylbismuth and bisdiethylbismuth.

(i). Spontaneous Decomposition of Diphenylbismuth Sodium in Liquid Ammonia.

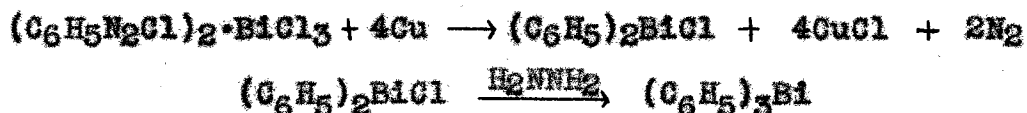
The spontaneous decomposition of diphenylbismuth sodium in liquid ammonia leads to the formation of triphenylbismuth in 49.1% yield(51).

Sodium-bismuth alloy and iodobenzene do not form triphenylbismuth in liquid ammonia due probably to the insolubility of the alloy in this solvent(51).

(j). Decomposition of an Aryldiazonium Chloride-Bismuth Chloride Complex Followed by Treatment with Ammonia or Hydrazine.

Gilman and Svigoon(48) were the first to report the preparation of triaryl bismuth compounds by the decomposition of an aryl diazonium chloride-bismuth chloride

complex by copper followed by treatment with ammonia. Gilman and Yablunsky(52) have established the mechanism of this reaction by isolating the intermediary  $\text{RBiX}_2$  and  $\text{R}_2\text{BiX}$  compounds. They have found also that hydrazine is a reagent of choice for conversion of these intermediates to  $\text{R}_3\text{Bi}$  compounds.

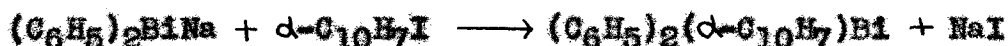


This reaction appeared to hold many possibilities for the preparation of organobismuth compounds possessing water-solubilizing groups. Thus far, however, it has not been possible to obtain experimental conditions favorable to the preparation of compounds such as tri-p-carboxyphenylbismuth or tri-p-sulfophenylbismuth. In any case, the reaction has many merits, since it has made possible the preparation of di-p-carboethoxyphenylbismuth chloride, di-o-carboethoxyphenylbismuth chloride, and o-carboethoxyphenylbismuth dichloride which could not have been made so readily by other methods. It affords a simplified procedure, also, for the preparation of tri-p-bromophenylbismuth.

(k). Reaction Between an  $\text{R}_2\text{BiX}$  or  $\text{RBiX}_2$  Compound and the Grignard Reagent. This reaction was first used by Challenger (14) to prepare diphenyl-d-naphthylbismuth, and later by Norvick(90) to prepare diethylamylbismuth. Gilman and

Yablunsky(53) have used a modified procedure at low temperatures to prepare a large number of related  $R_2R'Bi$  compounds.

(l). Reaction Between a Diarylbismuth Sodium Compound and an Aryl Iodide or Bromide. Gilman and Yablunsky(51) have prepared unsymmetrical bismuth compounds by the reaction of an  $R_2BiNa$  compound and  $\alpha$ -iodonaphthalene in liquid ammonia. Some aryl bromides react also, but substituents ortho to the halogen inhibit reaction.



(m). Conversion of Triarylbismuth Dihalides to Triarylbismuth Compounds. Tri-m-tolylbismuth, because of its low melting point, is best purified as the pentavalent dichloride(111). Diphenyl- $\alpha$ -naphthylbismuth dichloride may be separated from triphenylbismuth dichloride by virtue of the insolubility of the latter compound in acetone(26). Gilman and Yablunsky(53) converted impure, oily unsymmetrical bismuth compounds to their dichlorides in order to facilitate purification. These halogens may be removed by hydrogen sulfide(84), ammonium sulfide(83), moist silver oxide(19, 43), sodium hydrosulfite, formaldehyde, sodium and alcohol, and dimethyl sulfate and alkali(111). Hydrazine hydrate is the reagent of choice for this reduction(49).

(n). Conversion of Arylbismuth Dihalides and Diarylbismuth Halides to Triarylbismuth Compounds. Gilman and

Yablunsky(49) have converted  $\text{RbIX}_2$  and  $\text{R}_2\text{BiX}$  compounds to  $\text{R}_2\text{Bi}$  in excellent yields by means of hydrazine hydrate.

Alcoholic ammonia has been used also but no data is available as to its effectiveness(23, 83).

(e). Formation of Trimethylbismuth by the Spontaneous Disintegration of Tetramethylradium D. Mortenson and Leighton(87) have investigated the molecular changes accompanying radioactive transformations by measuring the strength of the  $\beta$ -rays given off by tetramethyllead containing small quantities of tetramethylradium D. These authors were interested in determining whether the molecule was completely decomposed or whether it adjusted itself to the new valence conditions. The transformation of radium D into radium E and then into radium F is essentially a change of an atom of lead into bismuth and then into polonium. Radium D emits only  $\beta$ -rays which are too feeble to produce an appreciable effect upon an electroscope while radium E and F possess strong  $\alpha$ - and  $\beta$ -ray activity. By the examination of the vapor above the radioactive tetramethyllead these authors found indisputable evidence for the presence of radium E (presumably as trimethylbismuth) and radium F (presumably as dimethylpolonium). From this they concluded that the tetramethylradium D molecule was not completely broken down by radioactive transformation, but adjusted itself

to the new valence conditions by the loss of a methyl group and the completion of the electron pair by the acquisition of an electron from its surroundings. The disintegration involves the rupture of one bond only.

(p). Formation of Trimethylbismuth by the Exchange Between Tetramethyllead and Bismuth Metal. Leigh-Smith and Richardson(75) have obtained evidence which suggests that bismuth metal deposited presumably as the oxide on a metallic surface can exchange with lead in tetramethyllead to form trimethylbismuth. This they demonstrated in the following manner. A piece of gold which had been activated with  $\text{Th}(\text{B}+\text{C}+\text{C}')+\text{C}^{11}$ ) was immersed in an ether solution of tetramethyllead for two hours. Then a small quantity of the solution was introduced into a small pot inside a Wilson expansion chamber filled with nitrogen. As the solution evaporated from the pot, characteristic tracks of  $\text{Th}(\text{C}+\text{C}')$  were observed starting from parts of the chamber remote from the pot, thus proving that a volatile compound had been formed which evaporated with the rest of the solution, and this compound, presumably, is trimethylbismuth. This exchange process occurs apparently between atoms of the same atomic number and without the breaking up of the molecule.

(q). Preparation of Tributylbismuth by Metal-Metal Interchange Between Butyllithium or Butylsodium and

Triarylbismuth Compounds. Gilman, Yablunsky and Svigoon (54) have found that the reaction between butyllithium or butylsodium and a triarylbismuth compound does not lead to the expected metalation of the aromatic nuclei but instead a metal-metal interchange occurs.

$$(p\text{-CH}_3\text{C}_6\text{H}_4)_3\text{Bi} + 3n\text{-C}_4\text{H}_9\text{Li} \longrightarrow (n\text{-C}_4\text{H}_9)_3\text{Bi} + 3p\text{-CH}_3\text{C}_6\text{H}_4\text{Li}$$

Talalaeva and Kocheshkov (113) have obtained phenyllithium from triphenylbismuth and lithium. Phenyllithium and bismuth did not yield triphenylbismuth, whereas phenyllithium and antimony gave triphenylantimony. This again demonstrates the sharp differences between antimony and bismuth. Many reactions which can be used to prepare organoantimony compounds in good yields fail entirely in the preparation of organobismuth compounds.

(r). Reaction Between an  $\text{R}_3\text{Bi}$  Compound and  $\text{RX}$ . Marquardt (81) has reported that in the course of heating tri-isobutylbismuth with methyl and ethyl iodide at  $150^\circ$  he obtained no quaternary iodide but instead trimethyl- and triethylbismuth, respectively.

(s). Electrolysis of Ethylsodium in Diethylsine Using Bismuth as the Anode. The electrolysis of an ethylsodium-diethylsine solution gives free ethyl radicals. Triethylbismuth was obtained when the electrolysis was carried out with bismuth as the anode (55b).

### Organobismuth Compounds

#### Trialkylbismuth compounds

The trialkylbismuth compounds are heavy, highly refractive, colorless or pale yellow, oily liquids. Tricyclohexylbismuth appears to be a solid at room temperature. The methyl and ethyl compounds possess unpleasant odors but the higher homologs are odorless. Their vapors irritate mucous membrane. Because of their inflammability in air they must be isolated under an inert atmosphere, and with the exception of the trimethyl compound they cannot be distilled at ordinary pressures without decomposition. Dunhaupt(34) has reported that the presence of water or ether makes possible a distillation of triethylbismuth at atmospheric pressure. Seifert(105) has found that it is possible to distill a trialkylbismuth etherate without decomposition. Triethylbismuth becomes cloudy when exposed to atmospheric oxygen and this clouding effect has been proposed as a delicate test for the presence of oxygen(47).

Moureu, Dufrasse and Badoche(88) have shown that trialkylbismuth compounds can function as both catalyst and inhibitor in the autooxidation of organic compounds. Triethylbismuth effectively retards the oxidation of benzaldehyde, furfural, butyraldehyde, and alkaline solutions of sodium sulfite but accelerates the oxidation of styrene, turpentine, and acid solutions of sodium sulfite.

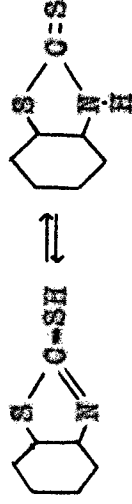
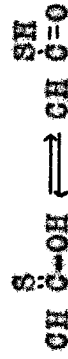
Trialkylbismuth compounds are unstable thermally and triethylbismuth explodes when heated to  $150^{\circ}$ . The thermal decomposition of trimethylbismuth yields free methyl radicals. These compounds burn in air with a greenish flame and expel thick yellow fumes. Their boiling points increase normally, and the branched chain compounds have lower boiling points than the normal isomers. Their specific gravities, as one might predict, decrease with increasing carbon content. They are soluble in alcohol, ether, petroleum ether, carbon tetrachloride, and benzene, and are insoluble in water. Prolonged boiling with water causes decomposition.

Trialkylantimony compounds combine readily with oxygen but the ease of oxidation decreases with increasing molecular weight. They ignite when warmed in air with the formation of  $Sb_2O_3$ . Trimethylantimony oxide and triethylantimony oxide can be prepared directly by the regulated oxidation of the tertiary compound. It has been reported that triamylantimony oxide can be prepared in this way, also. With chlorine, bromine, iodine, cyanogen bromide, cyanogen iodide, sulfur, and selenium, the trialkylantimony compounds form stable pentavalent compounds. They also form double salts with platinum and palladium chlorides. Mercuric, auric, and silver salts are reduced to the free metal. With alkyl halides they readily form stibonium halides. They dissolve in nitric acid to form dinitrates.

The trialkylbismuth compounds, in contrast, form no stable

pentavalent derivatives. With the exception of the trimethyl compound, which is the most stable of the trialkylbismuth compounds, they ignite spontaneously and burn to bismuth oxide, although the ease of oxidation decreases with increasing molecular weight. In the presence of pure oxygen, tributylbismuth explodes violently. The slow oxidation of an alkylbismuth compound leaves the organic radical as the aldehyde(54). With chlorine or bromine, trialkylbismuth compounds undergo cleavage even at 0° to form  $R_2BiX$  compounds. With sulfur there are formed complex mixtures(34). Inorganic acids cleave the bismuth compounds and with concentrated nitric and sulfuric acids the reaction proceeds explosively. With alkyl iodides quaternary bismuthonium iodides do not form even at elevated temperatures. Hydrogen sulfide cleaves the bismuth compounds. Silver nitrate or mercuric chloride readily cleave these compounds and are themselves reduced to the free metal.

Gilman and Nelson(47) have reported that triethylbismuth may be used for the detection of the -SH group. No cleavage of triethylbismuth occurs with the hydrogens in  $=NH$ ,  $-C\equiv CH$ , or simple -OH groups, although some strong carboxylic acids give limited reactions. There is no interference by azo or nitro groups. The existence of thioenolization in thioacetic acid and l-mercaptobenzothiazole, for example, is shown quite definitely.



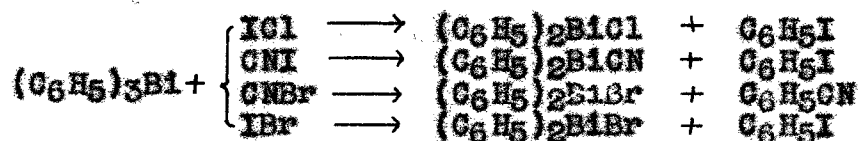
### Triarylbiarsenic Compounds

The tertiary aromatic biarsenic compounds are colorless, crystalline solids possessing a characteristic, pleasant odor. They are soluble in ethanol, ether, chloroform, ethyl acetate, acetone, petroleum ether, dioxane, and benzene and are insoluble in water. They are unaffected by oxygen and may be distilled without decomposition at very low pressures. They can be obtained in such a state of purity that triphenylbiarsenic has been used in the atomic weight determinations of bismuth (28, 29, 30). The molecular weights of triphenylbiarsenic, tri-*o*-naphthylbiarsenic, and tri-*p*-tolylbiarsenic determined cryoscopically in benzene are normal. This is further evidence that even the more stable aromatic compounds show no tendency to form biarsenic-bismuth bonds, even in view of their greater stability when the maximum valence has been satisfied. The aromatic groups are held loosely by bismuth and are cleaved readily by inorganic and organic acids, thiophenol, hydrogen, and inorganic halides.

With either chlorine or bromine, tertiary aromatic biarsenic compounds form dichlorides and dibromides, respectively.

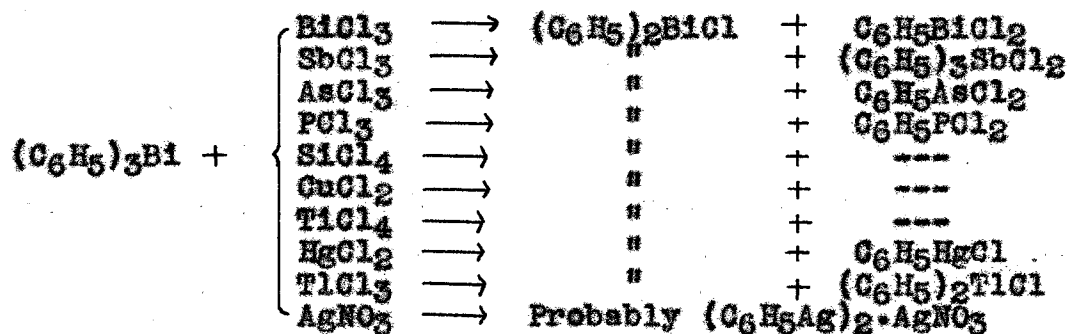
The diiodide is stable only at  $-78^{\circ}$ . It is formed by titrating triphenylbismuth at this temperature with iodine, using starch as the indicator. The end point occurs exactly when two equivalents of iodine have been added. Raising the temperature but a few degrees causes a spontaneous decomposition. If the temperature is kept at  $-78^{\circ}$ , however, the diiodide may be kept unchanged for days. The difluoride is prepared by double decomposition reaction between the dichloride and potassium fluoride.

With sulfuryl chloride, sulfur monochloride, and thionyl chloride tertiary compounds yield dichlorides(15, 18). With the halogen halides or halogen pseudohalides, ICl, IBr, CNCl, etc., the tertiary compounds are cleaved. The more negative group or atom attaches itself to the bismuth while the more positive group or atom is eliminated as part of the aromatic nucleus(17, 18, 19, 118). Information derived from such reactions lends further information to the stability series of halogens and pseudohalogens mentioned previously(p.15).



The ease with which bismuth exchanges its aromatic groups for the halogens of inorganic halides is evidence again of the weak carbon-bismuth bond. While triphenylantimony forms the dihalide under these conditions, triphenylbismuth undergoes

cleavage to yield  $R_2BiX$  and  $RBiX_2$  compounds(21, 23, 57, 59).



The reaction with silicon tetrachloride yields an unidentified organosilicon compound. There was no mention of the possible formation of organocopper compounds in the reaction with cupric chloride. No reduction to trivalent titanium occurs in the reaction with titanium tetrachloride. Considerable reduction occurs in the reaction between a Grignard reagent and titanium tetrachloride.

Stilp(108) has been the only one to report the formation of double salts in the reaction between tertiary aromatic bismuth compounds and mercuric chloride. Gillmeister(43) had reported previously that no double salt was formed between triphenylbismuth and mercuric chloride. Stilp did not prepare this salt but he was able to form others:  $(p\text{-CH}_3C_6H_4)_3Bi \cdot HgCl_2$ ,  $(o\text{-CH}_3C_6H_4)_3Bi \cdot HgCl_2$ ,  $(m\text{-(CH}_3)_2C_6H_3)_3Bi \cdot HgCl_2$ , and  $(\alpha\text{-C}_{10}H_7)_3Bi \cdot HgCl_2$ . The preparation of the tri-*p*-tolylbismuth double salt has been confirmed(55). These compounds are colorless crystalline solids which can be recrystallized safely from glacial acetic acid. They could be useful as derivatives because they possess sharp melting points and are

easily purified.

Challenger and Pritchard(21) have found that migration of phenyl groups from bismuth may be effected either to the comparatively electropositive tin and mercury or to electronegative elements such as arsenic and phosphorous. It was earlier proposed by Hilpert and Grüttner(67) that such migration took place only from the less positive to the more positive element, although the presence of halogens appeared to modify the reaction. The former authors consider that many of the ready migrations of phenyl groups are partly conditioned by the insolubility of one of the possible products.

With triphenylantimony, migration of phenyl groups occurs very rarely at ordinary temperatures. It has been observed with silicon tetrachloride, mercuric chloride, phosphorus trichloride, and with antimony trichloride only at 240°. Addition compounds are produced almost always with triphenylarsenic. This is further evidence of the stability of the bond between carbon and the more electronegative elements.

Organobismuth compounds do not add to benzaldehyde, benzalacetophenone(55), or Michler ketone(79). They do react, however, to a limited extent with acid halides(23) to give ketones in small yields. Under similar conditions, triphenylantimony does not react with acid halides. With chloroform in a sealed tube at 160° triphenylbismuth forms small quantities of triphenylmethane(26) and with benzyl chloride it forms diphenylmethane(23).

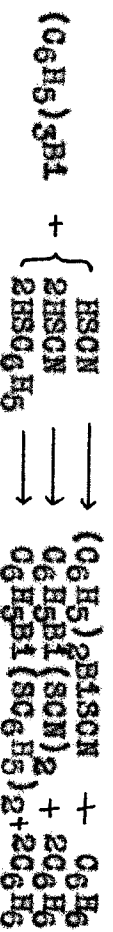
Challenger, Peters and Halevy(20) have attempted the preparation of triphenylbismuth diselenocyanate,  $(C_6H_5)_3Bi(SeCN)_2$ , by the interaction of triphenylbismuth dichloride and potassium selenocyanate,  $KSeCN$ . They obtained, instead, the unstable diphenylbismuth selenocyanate,  $(C_6H_5)_2BiSeCN$ . Tri-*p*-tolylbismuth dichloride and  $KSeCN$  gave a similar reaction. The instability of the pentavalent compound was to be predicted. Triphenylbismuth and tellurium dicyanide,  $Te(CN)_2$ , gave diphenylbismuth cyanide.

When triarylbi-smuth compounds are heated to high temperatures they decompose into the metal and biaryl compounds. Gambi(10) has found that triphenylbismuth and diphenylmercury form no double compound. Challenger and Ridgway(23) have reported the interchange of aromatic radicals between bismuth and mercury compounds at high temperatures. Tri- $\alpha$ -naphthylbismuth and diphenylmercury at  $200^\circ$  gave di- $\alpha$ -naphthylmercury, triphenylbismuth, and diphenyl- $\alpha$ -naphthylbismuth. Tri-*p*-tolylbismuth and diphenylmercury at  $180^\circ$  gave triphenylbismuth and di-*p*-tolylmercury. No exchange occurred between tri-*p*-tolylbismuth and di- $\alpha$ -naphthylmercury at this temperature(a).

(a). Calingaert and Beatty, *J. Am. Chem. Soc.*, **61**, 2748(1939) have described similar reactions as the "random intermolecular exchange of organic radicals." Thus, a mixture of tetraethyllead and tetramethyltin, after undergoing redistribution yielded all ten possible  $R_4M$  compounds. Later, Calingaert, Sorens and Thomson, *ibid.*, **62**, 1542(1940) showed that tetramethyllead and diethylmercury, and tetraethyllead and dimethylmercury, both underwent a similar reaction to yield all the possible redistribution products.

There appears to be an exchange of radicals when two bismuth compounds are fused, since tri- $\alpha$ -naphthylbismuth and triphenylbismuth at 190° yield diphenyl- $\alpha$ -naphthylbismuth. No reaction occurred between tri-*p*-tolylbismuth and tri- $\alpha$ -naphthylbismuth at 200°. There is evidence that the former reaction is reversible and recently Calingaert and co-workers(11) have proposed this reaction as an example of random distribution.

With strong inorganic acids triarylbi-smuth compounds are cleaved quantitatively to the hydrocarbon and the inorganic bismuth salt(84). With the more weakly acidic compounds it is possible to isolate intermediate products(25, 55).



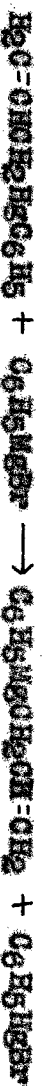
Triphenylantimony is not cleaved by thiophenol under similar conditions(55). Tri- $\alpha$ -naphthylbismuth is not cleaved by this reagent under conditions which give 45.6% cleavage with tri-phenylbismuth. Cleavage reactions with the halogens and pseudohalogens also indicate that the  $\alpha$ -naphthyl radical is held more firmly to bismuth than is the phenyl radical(17, 18).

Challenger and Ridgway(23) have observed that the  $\alpha$ -naphthyl radical has a greater affinity for mercury than has the phenyl or tolyl radicals. In an unusual reaction they found that  $\alpha$ -naphthylmagnesium bromide and phenylmercuric bromide gave di- $\alpha$ -naphthylmercury and phenylmagnesium bromide.



Only traces of diphenylmercury were obtained. The di- $\delta$ -naphthylmercury could not have formed by the disproportionation of the unsymmetrical phenyl- $\delta$ -naphthylmercury since this would have given equimolecular quantities of the two symmetrical forms(b).

(b). The explanation given by Challenger and Ridgway was satisfactory at the time that it was presented but more recently Kharrasch and Swartz, J. Org. Chem., **3**, 405(1938) and Gilman and Jones, Unpublished Studies, Iowa State College, have given a more logical explanation. Kharrasch and Swartz found that allylmercuric iodide and an excess of phenylmagnesium bromide gave a good yield of diphenylmercury. With one equivalent of phenylmagnesium bromide and allylmercuric iodide they obtained phenylmercuric bromide and a small quantity of allylphenylmercury. Phenylmercuric bromide and an excess of allylmagnesium bromide gave allylphenylmercury. Their explanation of these reactions are given as follows.



Gilman and Jones have shown that diphenylmercury and p-tolylmagnesium bromide gave di-p-tolylmercury in 80% yield. Di-p-tolylmercury is insoluble in ether and precipitates out of solution causing the equilibrium to shift continually towards the formation of the least soluble mercurial. In the reaction of Challenger and Ridgway, di- $\delta$ -naphthylmercury is much less soluble in ether than is phenyl- $\delta$ -naphthylmercury. Thus, the initially formed unsymmetrical mercurial reacted with the additional  $\delta$ -naphthylmagnesium bromide to form di- $\delta$ -naphthylmercury.



Thus, it is the insolubility of the di- $\delta$ -naphthylmercury and not the affinity of the  $\delta$ -naphthyl radical for mercury that determined the course of the reaction.

This anomalous behavior of the  $\alpha$ -naphthyl radical could not have been predicted on the basis of the Kharasch Electro-negativity Series which places the  $\alpha$ -naphthyl group far above the phenyl. A discussion of these and other exceptions to the Series will be given in the section dealing with Unsymmetrical Organobismuth Compounds.

Triphenylbismuth reacts with benzoyl peroxide to form triphenylbismuth dibenzoate,  $(C_6H_5)_3Bi(O_2CC_6H_5)_2$  (27) and with benzoyl nitrate to form triphenylbismuth dinitrate (118). It has been reported that triphenylbismuth gives color reactions with certain nitro derivatives (15).

Tribenzylbismuth oxidized spontaneously when exposed to air yielding benzaldehyde and inorganic bismuth (23, 55). Tri- $\beta$ -phenylethylbismuth undergoes a similar oxidation. This may account for the reported failure to prepare tri- $p$ -methoxybenzylbismuth and tri- $o$ -methoxybenzylbismuth (111). It has been reported also that bromophenacetin,  $p$ -chlorophenol, and  $o$ -iodoaniline and sodium-bismuth alloy do not yield tertiary bismuth compounds (100).

Makarova and Nesmeyanov (78) have prepared benzene-diazonium nitrate by the reaction between triphenylbismuth, nitric oxide, and nitrogen trioxide. Supniewski and Adams (111) were unable to obtain triaryl bismuth compounds possessing amine groups by reduction of trinitroaryl bismuth compounds. Unstable mixtures were the only products. Gilman and Yablunsky

(53) have prepared tri-p-dimethylaminophenylbismuth but this compound was cleaved by acetic acid in preference to forming a water-soluble acetate. It was cleaved also by chlorine even at 0° so that the preparation of a more stable pentavalent derivative was not possible.

TABLE I  
TERTIARY BISMUTH COMPOUNDS \*

Compound	M.p. or B.p., °C.	References
Tri- <u>o</u> -anisyl-	171	108, 110, 111
Tri- <u>p</u> -anisyl-	190	43, 108, 110
Tribenzyl-	85	14, 26, 55
Tribiphenyl-	183	120
Tri- <u>p</u> -bromophenyl-	149	23, 52
Tri- <u>p</u> -carboxyphenyl-	162	110
Tri- <u>o</u> -chlorophenyl-	141	53
Tri- <u>p</u> -chlorophenyl-	116	23, 52, 54
Tri-2- <u>p</u> -cymyl-	87	53
Tri- <u>p</u> -cumyl-	159	43
Tri- <u>p</u> -dimethylaminophenyl-	230	53
Tri- <u>p</u> -fluorophenyl-	94	53
Trimesityl-	135	53, 121
Tri- $\alpha$ -naphthyl-	235	14, 52, 54, 108
Tri- $\beta$ -naphthyl-	84	108
Tri- <u>p</u> -nitrophenyl-	121	109, 111
Trinitrophenyl-	159	118
Tri-2-nitro- <u>p</u> -tolyl-	126	111
Tri- <u>o</u> -phenetyl-	122	54
Tri- <u>p</u> -phenetyl-	73	43, 54
Tri- $\beta$ -phenylethyl-	---	55

TABLE I (Cont'd.)

Triphenyl-	77.6	14, 18, 29, 67, 83, 84 97, 100, 108, 121
Tristyryl-	-----	37
Trithymyl-	-----	37
Tri- $\alpha$ -thienyl-	137.5	72
Tri- <u>o</u> -tolyl-	129	43, 52, 108, 110
Tri- <u>m</u> -tolyl-	65	18
Tri- <u>p</u> -tolyl-	120	15, 48, 52, 54, 83, 108, 109
Tri- <u>m</u> -xylyl-	175	83, 108, 110
Tri- <u>p</u> -xylyl-	194.5	43, 108
Diphenyl- $\alpha$ -naphthyl-	119	14, 18, 23, 51, 53
Di- <u>p</u> -tolyl- $\alpha$ -naphthyl-	130	51, 53
Di- <u>p</u> -chlorophenyl- $\alpha$ -naphthyl	139	51, 53
Di- <u>p</u> -anisyl- $\alpha$ -naphthyl-	136	53
Di- <u>p</u> -phenetyl- $\alpha$ -naphthyl-	132	53
Dimesityl- $\alpha$ -naphthyl-	151.5	53
Di- <u>p</u> -chlorophenyl- <u>o</u> -tolyl-	104.5	53
Di- <u>p</u> -tolyl- <u>p</u> -chlorophenyl-	97	53
Di- <u>o</u> -tolyl- $\alpha$ -naphthyl-	114	53
Diphenyl- <u>p</u> -chlorophenyl-	83.5	53
Diphenyl- <u>p</u> -hydroxyphenyl- (?)	180	51

TABLE I (Cont'd.)

Trimethyl-	110/760mm.	66,75,80,81,87, 92,93
Triethyl-	96/50mm. 107/79 123/150	8,31,34,36,47, 76,80,81,93
Tri- <u>n</u> -propyl-	87/8mm. 127/50	31
Tri- <u>n</u> -butyl-	124/7mm. 173/50	31,56
Tri- <u>tert</u> -butyl-	dec.	55
Tri- <u>iso</u> -butyl-	162/74mm.	15,81
Tri- <u>n</u> -amyl-	158/7mm. 209/50	31
Tri- <u>iso</u> -amyl-	200/70mm.	81
Tricyclohexyl-	---	17,62,112
Diethylamyl-	---	90
Ethylcyclopentamethylene-	118/20mm.	63
Trilauryl-	---	107
Tricetyl-	---	107

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\*Where more than one value for a melting point is given,  
the highest value is recorded in this and other Tables.

Compounds of the General Formulas  $R_2BiX$  and  $RBiX_2$

Alkyl Compounds

Alkyl bismuth compounds of the type  $R_2BiX$  (where X is Cl or Br) are crystalline solids which burn spontaneously in air and must, therefore, be isolated under an inert atmosphere. They are soluble in alcohol and insoluble in ether. They have been prepared by the following methods:

(a). Reaction Between a Trialkylbismuth Compound and Chlorine or Bromine. The cooled ether solution of the trialkylbismuth compound is treated with the calculated quantity of the halogen(80, 81).

(b). Reaction Between Tetraethyllead and Bismuth Chloride. The reaction between tetraethyllead and bismuth chloride yields a colorless solid which ignites spontaneously in air and appears to consist in part of diethylbismuth chloride(50).

Compounds of the general formula  $RBiX_2$  are more stable than the type discussed above. These, too, are solids, possessing high melting points and are stable in air. They are somewhat soluble in alcohol and almost insoluble in ether and petroleum ether. The following methods have been employed in their preparation:

(a). Reaction Between a Bismuth Halide and a Tertiary Bismuth Compound. To a solution of bismuth chloride or

bromide is added the calculated quantity of the bismuth compound. The  $\text{RBiX}_2$  compound separates out as a yellow powder(80, 81).

(b). Reaction Between a Grignard Reagent and a Bismuth Halide. Methylbismuth dibromide has been prepared in small yields by the reaction between methylmagnesium iodide and bismuth bromide(114). Dimethylzinc and bismuth bromide also yield methylbismuth dibromide(80). Ethylbismuth dibromide has been obtained by the interaction of bismuth bromide and ethylmagnesium bromide(63).

(c). Reaction Between an  $\text{RBiCl}_2$  Compound and Potassium Iodide. Dunhaupt(34) prepared ethylbismuth diiodide by treating the corresponding dichloride with potassium iodide.

(d). Reaction Between a Tertiary Bismuth Compound and an Alkyl Iodide. Derivatives of the type  $\text{RBI}_2$  are produced when a tertiary bismuth compound and an alkyl iodide are heated to about  $200^\circ$ .

(e). Reaction Between a Tertiary Bismuth Compound and an Inorganic Halide. Inorganic halides, e.g., silver nitrate or mercuric chloride, readily cleave bismuth compounds and are themselves reduced to the free metal.

When an alkylbismuth dihalide is treated with aqueous ammonia or sodium hydroxide, an oxide,  $\text{RBiO}$ , is formed. This

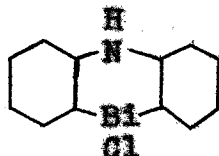
oxide is easily oxidized further by air. With ethylbismuth diiodide, alcoholic silver nitrate forms ethylbismuth dinitrate. Marquardt(50) has reported that dimethylbismuth bromide forms a double salt with zinc bromide. This double salt when treated with alcoholic ammonia yields methylbismuth oxide; with methyl iodide it forms methylbismuth diiodide; and with water it forms dimethylbismuth hydroxide.

#### Aryl Compounds

Aromatic bismuth halides of the general formula  $R_2BiX$  or  $RBiX_2$  are crystalline solids possessing high melting points. Prior to the recent publication by Gilman and Yablunsky(52) it was believed that all compounds of these types were very susceptible to moisture, alcohol, and ammonia. These authors were able to crystallize diphenylbismuth chloride from methanol. In addition they found that o-carbomethoxyphenylbismuth di-chloride, di-o-carbomethoxyphenylbismuth chloride, and di-o-carboethoxyphenylbismuth chloride were unaffected by moisture or alcohol and could be kept indefinitely without any precautions being taken.

Extensive studies of compounds like  $(C_6H_5)_3BiX_2$  have shown that the order of decreasing stability of the dihalides is  $R_3BiCl_2$ ,  $R_3BiBr_2$ ,  $R_3BiI_2$ . With  $R_2BiX$  compounds the order seems to be reversed based on ammonolytic and hydrolytic reactions, as well as conversion to  $R_3Bi$  by hydrazine(51).

The reaction between diphenylamine and bismuth chloride at 180-200° did not lead to the expected product,



since only a black tar was obtained(55). Refluxing diphenyl-  
bismuth chloride and sodium diethyloxalacetate,  $C_2H_5O_2CC(=O)CC(=O)O_2C_2H_5$ ,  
in dry benzene did not yield the desired coupling product.  
The only products were triphenylbismuth and inorganic bismuth  
(55).

Compounds of the general formula  $R_2BiX$  and  $RBiX_2$  have been obtained in a variety of ways.

(a). Reaction Between a Tertiary Bismuth Compound and Bismuth Halide. The calculated quantity of anhydrous bismuth chloride or bismuth bromide in dry ether is added to an ether solution of the tertiary bismuth compound. Two moles of bismuth compound and one of bismuth halide yield  $R_2BiX$  compounds.



The yields are very good, in many instances almost quantitative(53). The diarylbismuth chlorides are insoluble in organic solvents but they can be recrystallized from large volumes of dry benzene. The diarylbismuth bromides are slightly soluble in ether. If the molar ratio of bismuth halide and bismuth compound is reversed,  $RBiX_2$  compounds are formed.



Yields, here, are good, also. The dichlorides are extremely insoluble but the dibromides, with the exception of  $\alpha$ -naphthylbismuth dibromide, are quite soluble in ether. These are the best methods available for the preparation of these compounds.

(b). Reaction Between a Tertiary Bismuth Compound and an Inorganic Halide Other Than Bismuth Chloride. See p. 32.

(c). Reaction Between Tetraphenyllead and Bismuth Halide. Tetraphenyllead and bismuth bromide yield diphenylbismuth bromide and diphenyllead dibromide(58).

(d). Reaction Between an  $R_2BiCl$  Compound and Potassium Iodide. Diphenylbismuth iodide, di-*p*-chlorophenylbismuth iodide, and di-*p*-tolylbismuth iodide have been prepared by the interaction of the corresponding chloride and potassium iodide in absolute alcohol(7, 53).

(e). Reaction Between a Tertiary Compound and a Halogen, Halogen-Halide, or Halogen Pseudohalide. See p. 31.

(f). Reaction Between an  $R_2BiX$  Compound and a Halogen. Challenger(14) prepared phenylbismuth dibromide by treating diphenylbismuth bromide with bromine in chloroform. Diphenylbismuth bromide and iodine monochloride yielded phenylbismuth chlorobromide(16). Diphenylbismuth iodide and bromine gave phenylbismuth dibromide(16).

(g). Cleavage of a Tertiary Bismuth Compound During the Preparation of the Dichloride. Challenger and Wilkinson(26) have obtained small quantities of diphenylbismuth chloride during the preparation of triphenylbismuth dichloride from triphenylbismuth and chlorine. Considerable quantities of this compound are formed if the chloroform solution of the tertiary compound is not cooled in ice prior to the introduction of the chlorine(55).

TABLE II  
R<sub>2</sub>BIX AND RBIX<sub>2</sub> COMPOUNDS

Compound	M.P., °C.	References
Dibiphenylbismuth Chloride	---	120
Di-p-chlorophenylbismuth Chloride	160	53
Di-p-chlorophenylbismuth Bromide	159	23
Di-p-chlorophenylbismuth Iodide	140	23, 53
Di-d-naphthylbismuth Chloride	168	17, 18, 59
Di-d-naphthylbismuth Bromide (?)	---	17
Di-d-naphthylbismuth Iodide (?)	---	17
Diphenylbismuth Chloride	185	17, 18, 21, 23, 53
Diphenylbismuth Bromide	158	8, 14, 17, 53, 83
Diphenylbismuth Iodide	134	7, 17, 43, 53
Diphenylbismuth Selenocyanate	dec.	20
Diphenylbismuth Azide	168	22
Diphenylbismuth Cyanide	206	17, 20, 26
Diphenylbismuth Hydroxide	---	83, 100
Diphenylbismuth Thiocyanate	123.5	25, 26
Di-p-tolylbismuth Chloride	181.5	15, 18, 53, 59
Di-p-tolylbismuth Selenocyanate	---	20
Di-p-tolylbismuth Iodide	148	53
Di-o-carboethoxyphenylbismuth Chloride	148	51

TABLE II (Cont'd.)

Di-o-carbomethoxyphenylbismuth Chloride	181	51
Phenylbismuth Chlorobromide	---	17
Phenylbismuth Dibromide	206	14, 18, 53
Phenylbismuth Dichloride (?)	74	74
Phenylbismuth Diiodide	194	17
Phenylbismuth Dithiocyanate	186	25
p-Chlorophenylbismuth Dibromide	244	23
o-Naphthylbismuth Dibromide	208	14, 18, 53
p-Tolylbismuth Dichloride	207	18
o-Tolylbismuth Dibromide	181	53
Phenylbismuth Oxide	233	74
o-Carbomethoxyphenylbismuth Dichloride	221	51
o-Methoxyphenylbismuth Dibromide	171	55
Diethylbismuth Bromide	---	80
Diethylbismuth Iodide (?)	---	34
Dimethylbismuth Chloride	116	80
Dimethylbismuth Bromide	---	80
Dimethylbismuth Hydroxide	---	80, 81
Di-iso-butylbismuth Bromide	---	81
Di-iso-amylbismuth Bromide	---	81
Methylbismuth Dichloride	242	80
Methylbismuth Dibromide	214	80, 114

TABLE II (Cont'd.)

Methylbismuth Diodide	----	80
Methylbismuth Oxide	----	80,81
Methylbismuth Sulfide	(?)	81
Ethylbismuth Dichloride	----	34,80
Ethylbismuth Sulfide	(?)	34
Ethylbismuth Dibromide	----	34,80
Ethylbismuth Oxide	(?)	34
Ethylbismuth Diodide	----	34,80
Ethylbismuth Carbonate	(?)	34
<u>150-Butylbismuth Dibromide</u>	124	81
<u>150-Butylbismuth Diodide</u>	----	81
150-Amylbismuth Dibromide	134	81
Amylbismuth Dichloride	----	90
Cetylismuth Dibromide	----	107

A (?) following any compound indicates that its composition as indicated is open to some criticism, due either to the fact that the compound was not analyzed, or that the analyses given by the workers were not conclusive. In some instances, the author of this thesis, because of his experience, doubts the accuracy of reported observations.

### Pentavalent Bismuth Compounds

The pentavalent bismuth derivatives are the most stable of the organobismuth compounds. They are crystalline solids which are soluble in chloroform, dioxane, benzene, and acetone, and insoluble in alcohol and ether.

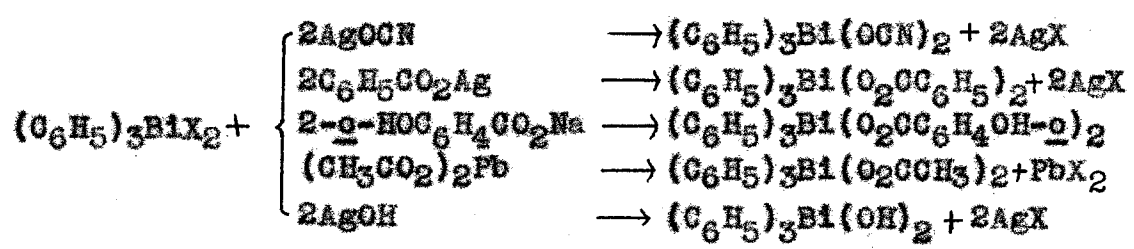
Tertiarybismuth dichlorides may be prepared by passing a stream of dry gaseous chlorine through the ice-cold solution of the tertiary compound in chloroform until an excess of the gas is present. The chloroform is then partially evaporated and the addition of several volumes of methanol precipitates the dichloride in a high state of purity. The yields are generally better than 90%. An alternative method is to pass a stream of dry chlorine over a petroleum ether solution of the tertiary compound. This method has the disadvantage that tertiarybismuth compounds are not very soluble in this solvent and it is necessary to work with large volumes of solution. Its advantage, however, is that the dichloride which forms is insoluble in petroleum ether and separates out immediately. Thus, nuclear chlorination is not possible. Trimethylbismuth forms a dichloride readily in this solvent(121), but if the preparation is carried out in benzene or chloroform nuclear substitution occurs(53). Sulfuryl chloride, sulfur monochloride, thionyl chloride(15, 18) and iodine trichloride(19) also yield dichlorides when reacted with tertiary bismuth com-

pounds but some cleavage occurs simultaneously.

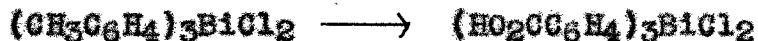
Triphenylbismuth difluoride is prepared by the interaction of triphenylbismuth dichloride and potassium fluoride.

Triarylbiismuth dibromides are prepared by the dropwise addition of a solution of bromine in carbon tetrachloride to an ice-cold solution of the tertiary compound in chloroform or petroleum ether. The first slight excess of bromine is easily visible and can be used to indicate the end-point of the reaction. From chloroform the dibromide is isolated by partial evaporation of the solvents and precipitation with methanol. The dibromide separates out of the petroleum ether directly. Yields are generally about 90%.

The halogens in  $R_3BiX_2$  compounds are quite labile and undergo double decomposition reactions readily.



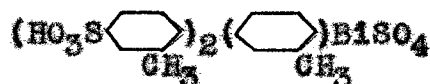
Supniewski and Adams(111) have reported that the side chains of tri-o- and tri-p-tolylbismuth dichlorides are oxidized by potassium permanganate, lead tetraacetate, or chromic acid. Yields range from 15 to 25%.



These compounds are soluble in alkali but upon reprecipitation

by hydrochloric acid yield low melting solids. Alkaline solutions of these compounds appear to be unstable and deposit a yellow solid on standing. The tri-1,3-xylylbismuth dichloride and the tri-m-tolylbismuth dichloride were oxidized also but the products were not isolated. The permanganate oxidation appears difficult to repeat(55).

Supniewski(110) was the first to report the successful nuclear sulfonation of tri-o-tolylbismuth dichloride. He obtained two compounds, 4-sulfo-2-methylphenyldi-o-tolylbismuth sulfate and a corresponding di-4-sulfo-2-methylphenyl-o-tolylbismuth sulfate.



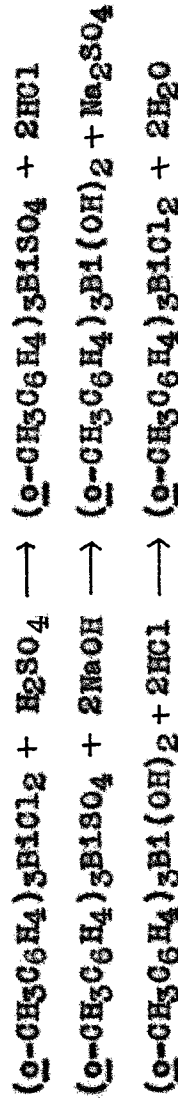
These compounds were soluble in alkali and were precipitated by acid. Once precipitated by acid, however, they did not redissolve readily in alkali.

Because of the many possibilities in this reaction for the preparation of water-soluble organobismuth compounds, an attempt was made to repeat this work. Tri-o-tolylbismuth dichloride dissolved readily in 98% sulfuric acid, evolving hydrogen chloride, and pouring the sulfuric acid solution on ice precipitated a white solid which dissolved readily in alkali. Acidification with hydrochloric acid yielded a product which did not dissolve again in alkali and was identified eventually

as tri-o-tolylbismuth dichloride by melting point, mixed melting point, and analysis.

It is well known that triphenylbismuth sulfate will dissolve in alkali to form the water-soluble triphenylbismuth dihydroxide(19). Although the analyses by Supniewski for these two sulfonic acids check with the theoretical for carbon and hydrogen, no sulfur analyses are given. In addition, the melting point of tri-o-tolylbismuth dichloride, 162°, is very close to the melting point of the monosulfonic acid, 167°. Since triphenylbismuth sulfate does not melt even at 284°, the reported melting point seems to be decidedly out of line. The melting point for the disulfonic acid is reported as 174° and this, too, appears unreasonably low.

It would appear that no nuclear sulfonation had occurred. Instead, the reaction with 98% sulfuric acid led only to the formation of tri-o-tolylbismuth sulfate which dissolved in alkali to form the water-soluble dihydroxide(which has been prepared). Acidification with hydrochloric acid converted the dihydroxide to the dichloride. The equations for these reactions are given as follows:



The nuclear nitration of aromatic bismuth compounds is carried out successfully only at comparatively low tempera-

tures and with the triarylbi-smuth dinitrates. In order to form the corresponding trinitro-derivative, triphenylbi-smuth dinitrate was nitrated at 0° for twelve hours with fuming nitric acid, and tri-p-tolylbi-smuth dinitrate for two hours at room temperature(111). Wilkinson and Challenger(118) have prepared a hexanitro-derivative by nitration at -10° for sixty-eight hours.

The orienting influence of bi-smuth in triarylbi-smuth compounds is not easily determined since the compounds are decomposed easily by fuming nitric acid. A neutral nitrating agent, benzoyl nitrate, and triphenylbi-smuth yielded only triphenylbi-smuth dinitrate(118).

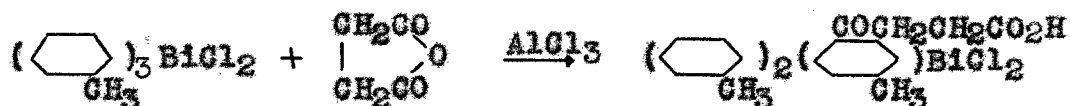
The nitration of triphenylbi-smuth dinitrate yields on the average, 86% of the meta, 12% of the ortho, and 2% of the para isomers(24, 115). Supniewski and Adams(111) and Supniewski(109, 110) have reported several nitro derivatives but they have not presented any structural proof for their compounds.

Triarylbi-smuth dihydroxides are prepared by treating the dichloride or dibromide with moist ammonia or silver hydroxide. The reaction proceeds through two steps so that it is possible to isolate the hydroxyhalide. The dihydroxide will oxidize ethyl alcohol to acetaldehyde, isopropyl alcohol to acetone, and n-propyl alcohol to propionaldehyde(22). With carbon dioxide the dihydroxide forms a carbonate and with

hydrochloric acid it forms a dichloride.

Challenger and co-workers(15, 19, 26) have reported the formation of an intense transient purple color when an aromatic pentavalent dihalide is treated with an aromatic Grignard reagent. They have suggested as an explanation the momentary formation of compounds of the type  $R_3BiR'_2$  analogous to the colored triphenylmethylnitrammonium and benzylnitrammonium described by Schlenk and Holtz (103, 104).

Gilman, Yablunsky and Svigoon(56) have attempted the preparation of water-soluble organobismuth compounds by the reaction between maleic or succinic anhydride and a triaryl-bismuth dichloride.



If mild conditions were employed the triaryl-bismuth dichloride was recovered unreacted. When more drastic conditions were employed the bismuth compound was partially or wholly destroyed without any indication of the desired reaction having occurred.

Supniewski and Adams(111) attempted to cleave the ether linkage in tri-p-anisylbismuth dibromide with hydriodic acid and with aluminum chloride. These reactions resulted only in complete decomposition or the recovery of unchanged bismuth compound. Similarly, an attempted lateral bromination in the presence of ultra-violet light of tri-p-tolylbismuth dibromide

and tri-*p*-tolylbismuth dibromide resulted only in cleavage of the carbon-bismuth linkage. When triphenylbismuth dichloride, ethyl chloroacetate, and copper bronze were refluxed in chloroform only triphenylbismuth was obtained. There was no evidence that the pentavalent compound had formed(55).

Triphenylbismuth hydroxychloride when treated with hydrobromic acid did not give triphenylbismuth chlorobromide. The products isolated were equimolecular quantities of triphenylbismuth dichloride and -dibromide(17). No compounds of the type  $R_3BiXX'$  have been prepared although phenylbismuth chlorobromide can be prepared in 77% yield.

## PENTAVALENT BISMUTH COMPOUNDS

TABLE III

Compound	M.P., °C.	References
Triarylbismuth Difluorides		
Triphenyl-	159	26
Triarylbismuth Dichlorides		
Tri- <i>o</i> -anisyl-	174	108, 110
Tri- <i>p</i> -anisyl-	133	110
Trichloro- <i>p</i> -anisyl-	133	43
Triphenyl-	200	120
Tri- <i>p</i> -bromophenyl-	155	23
Tri- <i>p</i> -chlorophenyl-	170	23, 55
Tri- <i>p</i> -cunyl-	208	43
Tri- <i>o</i> -cunyl-	164	53
Trimethyl-	150	121
Dichlorotrimethyl-	150	53
Tri- <i>d</i> -naphthyl-	174	18, 19, 55
Triphenyl-	141.5	15, 19, 25, 83, 84, 109, 121
Tri- <i>o</i> -carboxyphenyl-	159	110, 111
Tri- <i>o</i> -carbomethoxyphenyl-	137	110
Tri- <i>p</i> -carboxyphenyl-	130	109, 111
Tri- <i>p</i> -carbomethoxyphenyl-	107	110, 111

TABLE III (Cont'd.)

Trinitrophenyl-	128	118
Tri- <u>p</u> -nitrophenyl-	134	109,111
Dinitrotriphenyl-	136	43,118
Tetranitrotriphenyl-	146	118
Mononitrotriphenyl-	110	118
Hexanitrotriphenyl-	148	118
Tri- <u>p</u> -carbomethoxy- <u>o</u> -nitro-phenyl-	260d.	110,111
Tri- $\alpha$ -thienyl-	---	73
Tri- <u>o</u> -tolyl-	162	43,108,110
Tri- <u>m</u> -tolyl-	133	111
Tri- <u>p</u> -tolyl-	147	18,83,108,109
Tri-3-nitro- <u>o</u> -tolyl-	150	110,111
Tri-2-nitro- <u>p</u> -tolyl-	156	109,111
Tri- <u>m</u> -xyl-yl-	161	83
Tri- <u>p</u> -xyl-yl-	167.5	43,110
Diphenyl- $\alpha$ -naphthyl-	142	26
Di- <u>p</u> -tolyl- $\alpha$ -naphthyl-	147	53
Di- <u>p</u> -chlorophenyl- $\alpha$ -naphthyl-	132	53
Di- <u>p</u> -chlorophenyl- <u>o</u> -tolyl-	133	53
Di- <u>o</u> -tolyl- $\alpha$ -naphthyl-	140	53
Diphenyl- <u>p</u> -tolyl-	110	53

TABLE III (Cont'd.)

Triarylbiisnuth Dibromides

Tri- <u>o</u> -anisyl-	101	108
Tri- <u>p</u> -anisyl-	103	43,111
Tribiphenyl-	d.	120
Tri- <u>p</u> -bromophenyl-	107d.	23
Tri- <u>p</u> -chlorophenyl-	105	23
Tri- <u>p</u> -cumyl-	150	43
Tri-2-cymyl-	103	53
Trimesityl-	above 250 93d.	121 53
Tri- <u>o</u> -naphthyl-	124	14,108
Tri- <u>o</u> -phenetyl-	128	53
Triphenyl-	124	14,83,84
Tri- <u>o</u> -tolyl-	127	43,108,110
Tri- <u>m</u> -tolyl-	52	21,111
Tri- <u>p</u> -tolyl-	114	83,108,109
Tri- <u>m</u> -xyl-yl-	117	83
Tri- <u>p</u> -xyl-yl-	130	43
Diphenyl- <u>o</u> -naphthyl-	140	19,26
Di- <u>p</u> -tolyl- <u>o</u> -naphthyl-	127	53
Di- <u>p</u> -chlorophenyl- <u>o</u> -naphthyl-	103	53
Di- <u>p</u> -chlorophenyl- <u>o</u> -tolyl-	110	53
Di- <u>o</u> -tolyl- <u>o</u> -naphthyl-	122	53

TABLE III (Cont'd.)

Triarylbismuth Diiodides

Triphenyl-	Stable at -78	118
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Triarylbismuth Hydroxychlorides

Triphenyl-	161	19,22
Tri- <u>p</u> -tolyl-	154d.	108
Trihydroxy- <u>o</u> -tolyl-	154	111

Triarylbismuth Hydroxybromides

Triphenyl-	148	19
Tri- <u>p</u> -tolyl-	140	108
Tri- <u>m</u> -xyl-yl-	250d.	108

Triarylbismuth Dinitrates

Tribiphenyl-	162d.	120
Triphenyl-	130d.	83,109,118
Tri- <u>p</u> -carbomethoxy- <u>o</u> -nitro-phenyl-	160d.	111
Tri- <u>m</u> -nitrophenyl-	145d.	24,115
Tri- <u>p</u> -nitrophenyl-	147d.	109,111
Dinitrotriphenyl-	150d.	43
Tetranitrotriphenyl-	---	118
Mononitrotriphenyl-	---	118
Hexanitrotriphenyl-	---	118
Tri- <u>o</u> -tolyl-	60d.	43
Tri- <u>p</u> -tolyl-	---	83,109
Tri-2-nitro- <u>p</u> -tolyl-	160d.	109,111

TABLE III (Cont'd.)

Miscellaneous Pentavalent Derivatives

Triphenylbismuth Carbonate	Above 220	19,83
Triphenylbismuth Diazide	95	22
Triphenylbismuth Dicyanate	129	27
Triphenylbismuth Hydroxycyanide	135	22
Triphenylbismuth Oxide	120d.	15,22,83
Tri- <u>o</u> -tolylbismuth Oxide	100d.	55
Tri- <u>p</u> -tolylbismuth Oxide	109d.	55
Triphenylbismuth Sulfate	Above 284	15,19
4-Sulfo-2-methylphenyldi- <u>o</u> -tolylbismuth Sulfate	167	110
Tetranitrotriphenylbismuth Oxide	108d.	118
Di-4-sulfo-2-methylphenyl- <u>o</u> -tolylbismuth Sulfate	174	110

### Reactions in Liquid Ammonia

Diarylbiisnuth halides react smoothly with metals which dissolve in liquid ammonia to give deep red  $R_2BiM$  compounds. The metals examined have been lithium, sodium, potassium, calcium, and barium. The  $R_2BiM$  compounds decompose slowly to the corresponding  $R_2Bi$  compound and inorganic bismuth, but they are sufficiently stable to react promptly with  $RX$  compounds. This provides an additional avenue of approach to the preparation of unsymmetrical organobismuth compounds.



The reactivity of the  $R_2BiM$  compounds is due in part to their solubility in liquid ammonia for the insoluble sodium-bismuth alloy does not react with iodobenzene. Thus far it has not been possible to prepare these compounds directly from  $R_2Bi$  and the metal.



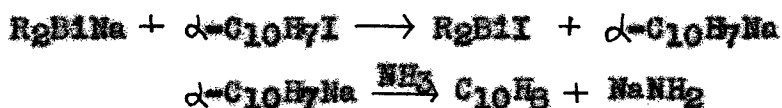
The reaction between an arylbismuth dibromide and sodium does not lead to the expected  $RBiNa_2$ .



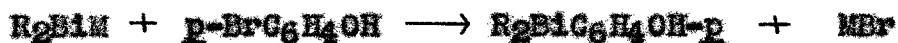
A complex decomposition occurs, instead, and the only products are  $RH$  and inorganic bismuth.

Mention has been made (p.12) of the possible existence of the diarylbismuth radical in liquid ammonia.

A metal-halogen interconversion(46) appears to take place in liquid ammonia between  $R_2BiM$  compounds and  $\alpha$ -iodo-naphthalene. In these reactions significant quantities (up to 34.6%) of naphthalene are formed in addition to the diphenyl- $\alpha$ -naphthylbismuth. The naphthalene very probably does not come from the following reaction which proceeds only to the extent of 47% :  $\alpha-C_{10}H_7I + 2Na \xrightarrow{NH_3} \alpha-C_{10}H_7Na \xrightarrow{NH_3} C_{10}H_8$ , since there is no free sodium in the  $R_2BiNa$  solutions. It appears, therefore, that the naphthalene may owe its formation to a new type of halogen-metal interconversion.



The liquid ammonia reactions make possible the preparation of water-soluble organobismuth compounds.



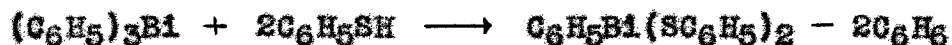
The phenolic compound was rather unstable as might have been predicted because of the lability of a hydroxyphenyl radical attached to a metal. The carboxylic derivative could not be obtained pure, due primarily to the relative inertness of halogens ortho and para to the functional group in benzoic acid and benzoates towards  $R_2BiM$  compounds in liquid ammonia. Such halogens are much less reactive in this medium than the halogens in a simple halogenated benzene or naphthalene. There was evidence, however, of the presence of a water-soluble bismuth compound.

Organobismuth Salts of Organic Acids

Trivalent Compounds

In studying the cleavage of tertiary bismuth compounds by thiophenol(p.11) Gilman and Yablunsky(55) were interested in the isolation of the cleavage products in order to determine their composition and possible therapeutic properties. It was of primary interest to determine what effect a  $C_6H_5S-$  group instead of a  $C_6H_5-$  group would have on the toxicity of bismuth in an organometallic molecule.

It was observed early in this work with triphenylbismuth and thiophenol that the only product obtained was the secondary cleavage product even though an equimolecular ratio of the two compounds was used.



This would indicate either of two possibilities: (1) that  $(C_6H_5)_2BiSC_6H_5$  is unstable or (2) that the second phenyl group was cleaved apparently with greater ease than was the first. This is in contradiction with the more general rule that a second R group is cleaved with greater difficulty than the first. Furthermore, Catlin(12) found that primary cleavage by means of hydrogen chloride is aided by chloroform as the solvent whereas secondary cleavage is aided by benzene. In this work it was found that the secondary cleavage of triphenylbismuth occurred preferentially in the absence of a solvent or in chloroform, benzene, or toluene.

Further work with tri-*p*-chlorophenylbismuth and tri-*p*-tolylbismuth indicated that here, too, the secondary cleavage was preferential, since the products obtained were  $p\text{-ClC}_6\text{H}_4\text{Bi}(\text{SC}_6\text{H}_5)_2$  and  $p\text{-CH}_3\text{C}_6\text{H}_4\text{Bi}(\text{SC}_6\text{H}_5)_2$ , respectively. Triphenylbismuth and methyl thio-salicylate also gave the corresponding secondary cleavage product,  $\text{C}_6\text{H}_5\text{Bi}(\text{SC}_6\text{H}_4\text{CO}_2\text{CH}_3\text{-}o)_2$ . If the experimental conditions were made quite drastic, e.g., a large excess of RSH compound and high temperature, all three R groups were cleaved. The anomalous behavior of tri-*d*-naphthylbismuth towards thiophenol has been noted before (p.34).

Kharasch(69) has reported a process for the preparation of water-soluble organobismuth compounds of the general formula  $\text{RBi}(\text{SeC}_6\text{H}_4\text{CO}_2\text{H-}o)_2$  by cleavage of  $\text{RBi}$  by seleno-salicylic acid. This again demonstrates the unusual tendency to cleave two R groups.

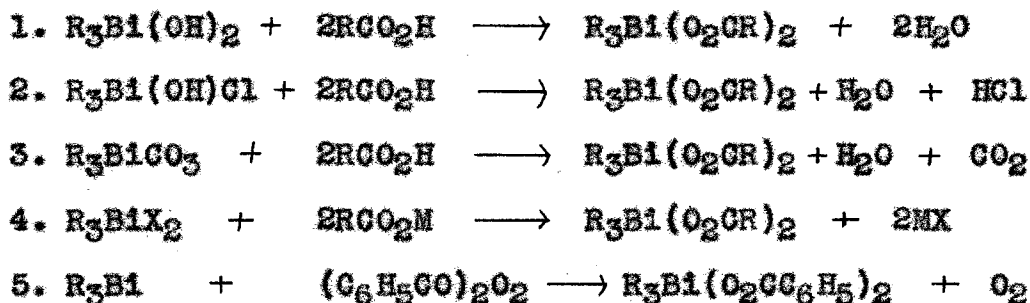
In the course of this study triphenylbismuth was cleaved with several aliphatic and aromatic carboxylic acids. With benzoic and cinnamic acids the products were  $\text{C}_6\text{H}_5\text{Bi}(\text{O}_2\text{CC}_6\text{H}_5)_2$  and  $\text{C}_6\text{H}_5\text{Bi}(\text{O}_2\text{CCH=CHC}_6\text{H}_5)_2$ , respectively, indicating again preferential cleavage of two R groups. With acetic, trichloroacetic, propionic, butyric, thio-glycolic, lactic, salicylic, and thio-salicylic acids the cleavage products were mixtures which could not be resolved because of the insolubility of these salts in water and

organic solvents. Koton(71) has described the complex products obtained by the cleavage of triphenylbismuth by formic and acetic acids when a large excess of these acids was employed.

It is of interest to point out that every compound possessing a carbon-bismuth-sulfur linkage which has been prepared was a deep yellow in color. The products obtained with the carboxylic acids were always white powders.

#### Pentavalent Compounds

Pentavalent Bismuth salts of the general formula  $R_3Bi(O_2CR)_2$  have been prepared by various methods(15, 19, 27, 111, 121).



Gilman and Yablunsky(55) employed reaction 3 to prepare a number of pentavalent derivatives in which the benzoyl radical possessed water-solubilizing groups. They prepared salts with anthranilic, p-aminobenzoic, salicylic, p-hydroxybenzoic, and phthalic acids. When they attempted to prepare amine hydrochlorides of triphenylbismuth dianthranilate or triphenylbismuth di-p-aminobenzoate the only products obtained were triphenylbismuth dichloride and the hydrochloride of the corresponding acid. With the disalicylate, di-p-hydroxybenzoate, and

di-o-carboxybenzoate there occurred complete dissociation into triphenylbismuth dihydroxide and the potassium salt of the acid when the compounds were treated with dilute potassium hydroxide solution.

Proof of the structure of these pentavalent compounds was achieved by cleavage with hydrochloric acid and the identification of the  $R_3BiCl_2$  and organic acid formed.

A rather interesting observation made during the course of this work was that when these derivatives were crystallized from acetone or benzene there was a general tendency to add molecules of solvent of crystallization. In several instances, as with tri-o-tolylbismuth disalicylate and triphenylbismuth dianthranilate the solvent was so integral a part of the crystal that any attempts to remove the solvent resulted in the decomposition of the compound.

TABLE IV

ORGANOBISMUTH SALTS OF ORGANIC ACIDS

Trivalent compound	M.P., °C.	References
$C_6H_5BI(SO_3H)_2$	1704.	55
$p-C_6H_4BI(SO_3H)_2$	1704.	55
$p-CH_2C_6H_4BI(SO_3H)_2$	1664.	55
$C_6H_5BI(SO_3CH_2CH_3)_2$	102	55

Pentavalent compound	M.P., °C.	References
Triphenylbismuth Diacetate	162	15, 19, 111, 121
Triphenylbismuth Diacetate- $\frac{1}{2}CH_3CO_2H$	137	19
Tri- <i>m</i> -tolylbismuth Diacetate	149	111
Tri- <i>p</i> -tolylbismuth Diacetate	162	111
Triphenylbismuth Dibenzate	173	27
Tri- <i>p</i> -tolylbismuth Dibenzate	1694.	55
Tri- <i>o</i> -tolylbismuth Diacetylate- $C_6H_6$	1654.	55
Diphenylbiphenylbismuth Dibenzate	147	51
Diphenyl- $\beta$ -naphthylbismuth Dibenzate	140	51
Triphenylbismuth Diacetate	178	55
Triphenylbismuth Diacetylate	1854.	55

TABLE IV (Cont'd.)

Triphenylbismuth Di- <u>o</u> -carboxybenzoate	169d.	55
Triphenylbismuth Di- <u>p</u> -hydroxybenzoate	Above 250	55
Triphenylbismuth Phthalate	165d.	55
Triphenylbismuth Di- <u>p</u> -aminobenzoate	148d.	55
Triphenylbismuth Di- <u>p</u> -aminobenzoate- 2CH <sub>3</sub> COCH <sub>3</sub>	148d.	55
Triphenylbismuth Dianthranilate·C <sub>6</sub> H <sub>6</sub>	102d.	55
Triphenylbismuth Dichloroacetate	156	55
Tri- <u>p</u> -chlorophenylbismuth Di-salicylate	187d.	55
Triphenylbismuth Dilactate	---	19
Triphenylbismuth Dicumphorsulfonate	---	19
Triphenylbismuth Ditartrate	---	15
Triphenylbismuth Dipicrate	---	15

TABLE V

## MISCELLANEOUS ORGANOBISMUTH COMPOUNDS

Compound	M.P., °C.	References
( <u>p</u> -CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi·HgCl <sub>2</sub>	234	108
( <u>o</u> -CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi·HgCl <sub>2</sub>	148	108
( <u>m</u> -(CH <sub>3</sub> ) <sub>2</sub> C <sub>6</sub> H <sub>3</sub> ) <sub>3</sub> Bi·HgCl <sub>2</sub>	160	108
( $\alpha$ -C <sub>10</sub> H <sub>7</sub> ) <sub>3</sub> Bi·HgCl <sub>2</sub>	193	108
(CH <sub>3</sub> ) <sub>2</sub> BiBr·ZnBr <sub>2</sub>	---	80

### Molecular Structure

Bergmann and Schütz(4) have found the dipole moment of triphenylbismuth to be zero. From this they have concluded that its structure is that of a plane triangle with the bismuth atom situated at the center of gravity. The triphenylphosphines, -amines, -arsines, and -stibines appear to be triangular pyramids. Pai(91), from studies of the Raman spectra of trimethylbismuth, has deduced that it possessed a pyramidal structure, the three methyl groups forming the triangular base and the bismuth atom the apex. From X-ray studies, Greenwood(61) has data which would indicate that triphenylbismuth dichloride has eight molecules in a unit cell.

### Crystal Structure

The crystal structure of triphenylbismuth(2), triphenylbismuth difluoride(26), and diphenylbismuth thiocyanate(26) have been studied. Michaelis and Marquardt(83) have reported two crystal forms of triphenylbismuth, one melting at  $75^{\circ}$  and the other at  $78^{\circ}$ . This has not been observed by other workers in this field. Drew and Landquist(33) and Pascal(95) have studied the triphenyl compounds of the elements of Group V for possible isomorphism. They have observed compatibility only with triphenylphosphorus and triphenylarsenic. No close

relationship such as can be found in the organometallic compounds of the elements of Group IV exists among those of the elements of this group.

Greenwood(60, 61) and Bryant(9) have studied the rotatory polarization of light by crystals of triphenylbismuth dichloride.

#### Phenomena With Light

Schaefer and Hein(101) have studied the absorption of light by trimethylbismuth, triphenylbismuth, and triphenylbismuth dichloride, and have observed that the first two compounds show normal curves and obey Beer's law. The dichloride absorbs light much more strongly than the tertiary compounds due to the two chlorine atoms and the higher valence of bismuth.

#### Therapeutic Applications of Bismuth

The therapeutic properties of bismuth were recognized as early as 1660. By 1750 it had been used in the treatment of gonorrhea and by 1779 in syphilis therapy. It was not until 1921, however, that research in the field of bismuth therapy became intense. With the pioneer work of Levaditi and his co-workers there began what may be called "The French School of Bismuth Therapy." In the six years immediately following Levaditi's first publication, nineteen hundred and sixteen articles on bismuth therapy were published, and by 1935, a

conservative estimate would have placed this number close to five thousand. By 1932 about two hundred and fifty organic and inorganic bismuth compounds had been prepared and investigated for possible therapeutic utilization.

The result is a state of chaos which confuses the investigator in the field. The actual value of organic bismuth compounds in spirochetosis has long been the subject of debate although their value in the intermittent treatment of syphilis by arsenicals is acknowledged. Bismuth is much more toxic than arsenic and acts more slowly. Its compounds can be injected intramuscularly only since intravenously their therapeutic index is about 1:3. This is true even for those compounds accepted as New and Non-Official remedies by the Council on Pharmacy and Chemistry of the American Medical Association. According to Dr. R. A. Vonderlehr, Assistant Surgeon General, Division of Venereal Diseases of the United States Public Health Service(116) "--It is the general consensus of opinion of experts in this country and particularly of the Cooperative Clinical Group that when all factors are taken into consideration, bismuth subsalicylate suspended in oil is probably the most practical bismuth preparation (for the treatment of syphilis)."

When injected intramuscularly bismuth compounds form "depots" which slowly release bismuth into the blood. In some instances absorption is so slow that there is still

evidence of bismuth at the point of injection after four hundred days.

Kolle(70) has found that such a depot in the ear of a rabbit will prevent the appearance of scrotal lesions following intratesticular injections of the syphilis virus. When the ear was amputated after three months, however, scrotal lesions developed after an interval of several weeks. This can mean perhaps that the virulent organisms were not destroyed by the bismuth but that their multiplication was inhibited. It is to be noted, however, that complete cures of syphilis by the use of organic bismuth compounds exclusively have been reported also.

Giemsa(39,40,41,42) has reported the remarkable healing properties of triphenylbismuth in experimental canine syphilis, relapsing fever, and nagana. He has proposed its use in the later stages of syphilis because of its lipid solubility which enable it to penetrate into the central nervous system undecomposed. Albrecht and Evers(1) and Schlossberger(102) were unable to confirm these favorable reports. Rothermundt and Wichmann(99) have reported that triphenylbismuth had no therapeutic activity in the treatment of mice infected with S.crociduræ or S.hispanica. Sellman and Seifter(107) have demonstrated ingenuity in testing some alkylbismuth compounds for their anti-syphilitic activity. They found that trimethylbismuth could be handled and was sufficiently soluble

In water to produce marked effects in experimental animals when treatment was by vein, inhalation, or skin. It had a definite healing effect in rabbit syphilis but it demonstrated no extraordinary therapeutic activity. The higher alkyls, triaurylbismuth, triacetylismuth, and cetylismuth dibromide were poorly absorbed and inactive.

Walker(117) has determined the least concentration of four organobismuth compounds which would destroy Goldium colpoda in three minutes. His results are as follows:

Triphenylbismuth	Mole/11,000
Diphenylbismuth Bromide	Mole/270,000
Tri- <i>p</i> -tolylbismuth	Mole/2000
Triphenylbismuth Dibromide	Mole/7100

From this one may observe that the secondary derivative, diphenylbismuth bromide, possesses the highest toxicity. This holds true generally inasmuch as  $(C_6H_5)_2SbX$  and  $(C_6H_5)_2AsX$  (where X is any halogen) are more toxic than the primary or tertiary derivatives of the same elements. Leaoq(74) has found  $C_6H_5AsCl_2$  to be more toxic than either  $C_6H_5SbCl_2$  or  $C_6H_5BiCl_2$ . Quinquevalent derivatives in this family are weakly toxic and it has been suggested that whatever toxic effects they possess is due to their first being reduced to the trivalent form.

It is apparent that little work has been done in bismuth therapy with organobismuth compounds. The principal objection

seems to be their high toxicity. If organobismuth compounds of low toxicity and high therapeutic value could be synthesized a more accurate estimation of their effectiveness would be possible.

#### Absorption of Bismuth by the Organism

If massage of the muscle follows an intramuscular injection of a bismuth compound, bismuth appears in the blood two hours after the injection. Without massage the appearance is delayed for twenty-four hours. The concentration of bismuth appears to be highest in the kidneys, less in the liver, spleen, and lungs. The blood and bile show varying content. Some of the bismuth may be stored in the liver and other organs, but the greater part is eliminated by the kidneys, liver, and intestinal mucosa. It appears in the urine from eighteen to twenty-four hours after the injection.

#### Physiological Action of Bismuth

Following an intramuscular injection of a bismuth compound there occurs a local necrosis of the muscle fibre which is slowly absorbed and replaced by scar tissue. Sometimes sterile abscesses are formed. The gluteal muscle mass is large enough to tolerate from fifty to a hundred or more injections without serious difficulty.

In bismuth poisoning of animals by a single large dose the chief pathological changes occur in the kidney and liver, other organs being affected little or not at all. In the kidneys there is marked tubular nephritis and degenerative changes similar to those produced by mercury poisoning. Intravenous injections produce these alterations more frequently than do intramuscular administrations. Of the local reactions pain is the most frequent and this is due, in part, to the vehicle. A compound in olive oil may be extremely painful; in peanut oil it is bland and non-irritating.

The administration of bismuth compounds in therapeutic doses at weekly intervals is, however, remarkably free from toxic effects. The one exception appears in the bluish-gray pigment line which forms on the gum margins of the mouth after a half-dozen injections. In rare instances (35 from the year 1922 to 1933) death may result from bismuth therapy but these have been due to accidental intravenous injection.

## Analytical Procedures

### Qualitative

A very convenient test for bismuth in an organobismuth compound is to burn a small portion of the compound on a clean spatula. The yellow-brown residue of bismuth oxide is easily recognized. Another method involves cleaving 0.05 g. of the compound with 3 cc. of concd. nitric acid and heating the solution to dryness. After allowing the residue to cool, it is taken up in 5 cc. of concd. hydrochloric acid, evaporated down to 1 cc. and then treated with a freshly prepared solution of sodium stannite. A heavy black precipitate of bismuth metal forms, if bismuth was present in the compound.

### Quantitative

Michaelis and Polis(84) have described the determination of bismuth in organobismuth compounds as  $\text{Bi}_2\text{O}_3$ . Challenger and Goddard(19) as  $\text{Bi}_2\text{S}_3$ , and Gilman and Yablunsky(52) as the phosphate,  $\text{BiPO}_4$ . The analysis as the phosphate seems to be the simplest of the three, requiring very little attention.

### Summary

An attempt has been made in the preceding Review to survey the literature on Organobismuth Compounds up to September, 1940. Those properties which are characteristically possessed by organobismuth compounds were stressed, and particular attention has been directed towards correlating the organometallic compounds of arsenic, antimony, and bismuth, to show gradations of stability, reactivity, and compound formation.

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## PART II. UNSYMMETRICAL ORGANOBISMUTH COMPOUNDS

### Introduction

In 1913, Challenger reported the beginning of an investigation on the preparation and resolution of optically active organobismuth compounds(1). From a superficial examination it appeared that the labile halogens in compounds of the types  $R_2BiX$  and  $RBiX_2$  should react with the Grignard reagent,  $R'MgX$ , to form  $R_2R'Bi$  and  $RR'_2Bi$  compounds.

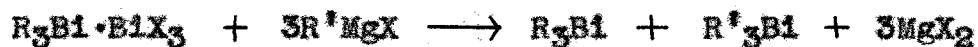


Actually mixed alkylarylantimony compounds have been prepared by this method(2).

Challenger and his co-workers(3, 4, 5, 6, 7) found, however, that when an aromatic  $R_2BiX$  compound was treated with an aromatic Grignard reagent,  $R'MgX$ , the product obtained was the symmetrical bismuth compound,  $R_3Bi$ . To them, this indicated the possibility that an  $R_2BiX$  compound might be in reality a mixture or perhaps a double salt of  $R_3Bi$  and  $BiX_3$ . This appeared reasonable because Stilp(8) has prepared a number of double salts of the general type  $R_3Bi \cdot HgCl_2$ .

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If such a double salt,  $R_3Bi \cdot BiCl_3$ , reacted with three equivalents of  $R'MgX$ , two products should have been formed.



Actually, they found that this did not occur except in reactions with an aliphatic Grignard reagent in which case the odor of the trialkylbismuth compound was noticed. This compound was not isolated. Its presence could have been explained easily as a product of the disproportionation of the initially formed unsymmetrical bismuth compound, but this would not explain the isolation of the  $R_3Bi$  compound only in the reaction with an aromatic Grignard reagent. In either case, two bismuth compounds should have been isolated.

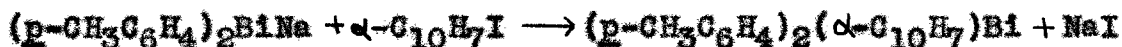


Challenger and Allpress(6) have reported that their yield of diphenyl- $\alpha$ -naphthylbismuth was increased if the reaction between  $\alpha$ -naphthylbismuth dibromide and phenylmagnesium bromide was allowed to proceed at room temperature for two weeks instead of at the reflux temperature of ether for five hours. Gilman and Yablunsky(9) observed that these two compounds reacted instantly even at  $0^\circ$  to yield diphenyl- $\alpha$ -naphthylbismuth in 57% yield whereas the highest yield reported by Challenger and Allpress was about 15%. They extended this low temperature reaction and were able

(9) Gilman and Yablunsky, J. Am. Chem. Soc., **62**, 600(1940).

to prepare a large number of new unsymmetrical  $R_2R'Bi$  compounds. In most instances the reaction product was an oil which was difficult to crystallize. It was found that cooling in the presence of methanol was generally successful in causing crystallization. In the preparation of di-o-tolyl- $\alpha$ -naphthylbismuth it was necessary to convert the oily reaction product to the dichloride which was purified and then reduced to a crystalline product by the recently described hydrazine method(10). It appeared at first that the  $\alpha$ -naphthyl radical was a necessary group in the unsymmetrical compound but later it was possible to prepare compounds like diphenyl-p-chlorophenylbismuth, di-p-tolyl-p-chlorophenylbismuth, di-p-chlorophenyl-o-tolylbismuth, etc. It was not possible to prepare diphenyltriphenylmethylbismuth. The product obtained appeared to be a mixture and was unstable.

In addition, Gilman and Yablunky(11) utilized liquid ammonia as a medium for the preparation of unsymmetrical compounds. Diarylbismuth halides reacted in liquid ammonia with sodium, potassium, lithium, calcium, and barium to form highly reactive  $R_2BiM$  or  $(R_2Bi)_2M$  compounds which upon treatment with  $\alpha$ -iodonaphthalene formed the corresponding unsymmetrical compound. For example, di-p-tolylbismuth sodium and  $\alpha$ -iodonaphthalene gave di-p-tolyl- $\alpha$ -naphthylbismuth.

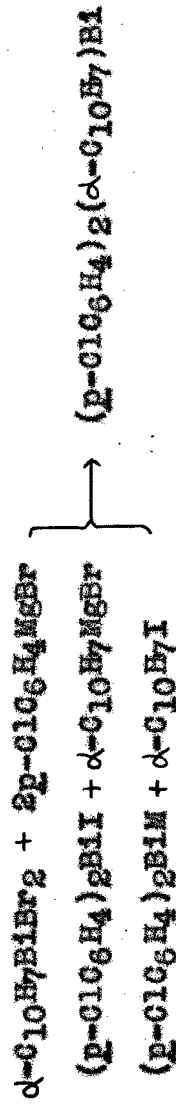


(10) Gilman and Yablunky, ibid., 62, 665(1940).

(11) Gilman and Yablunky, ibid., 62, 000(1940).

Some aryl iodides, e.g., o-iododimethylaniline, did not react indicating that steric hindrance inhibits or prevents reaction.

It becomes evident that unsymmetrical  $R_2R'Bi$  compounds can be prepared in essentially three different ways. The synthesis of di-p-chlorophenyl- $\alpha$ -naphthylbismuth will illustrate the methods which were applied successfully.



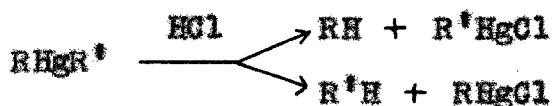
The samples of di-p-chlorophenyl- $\alpha$ -naphthylbismuth from each reaction were shown to be identical by the method of mixed melting points.

Once obtained in a pure state the unsymmetrical compounds were found to be quite stable. In this connection it is interesting to observe that ethylmethylmercury, previously reported to be quite unstable and easily subject to disproportionation, has been prepared by Calingaert and co-workers (12) and found to be stable provided traces of  $RHgX$  or other related catalysts are absent.

(12) Calingaert, Soroos and Hnizda, ibid., 62, 1107(1940).

The Preferential Cleaving of Radicals from Metals in  
Organometallic Compounds

When an unsymmetrical organomercury compound,  $\text{RHgR}^1$ , is cleaved by hydrogen chloride there is a preferential replacement either of R or  $\text{R}^1$ .



On the basis of a large number of reactions of this type Kharasch and co-workers(13, 14, 15, 16, 17, 18, 19, 20, 21) proposed a series of radicals based on their relative ease of cleavage from mercury. Since the radical which cleaved most readily combined with the hydrogen of the hydrogen chloride it was proposed that this was the more electronegative of the two radicals and the series could then be known as an Electronegativity Series. A survey of the elaborate studies of Kharasch and co-workers gives the following series of radicals in order of decreasing electronegativity.

- (13) Kharasch and Grafflin, J. Am. Chem. Soc., 47, 1948(1925).
- (14) Kharasch and Marker, ibid., 48, 3130(1926).
- (15) Kharasch and Reinmuth, J. Chem. Education, 5, 404(1928).
- (16) Kharasch and Reinmuth, ibid., 8, 1703(1931).
- (17) Kharasch and Flenner, J. Am. Chem. Soc., 54, 674(1932).
- (18) Kharasch, Reinmuth and Mayo, J. Chem. Education, 11, 82 (1934).
- (19) Kharasch, Pines and Levine, J. Org. Chem., 3, 347(1938).
- (20) Kharasch and Swartz, ibid., 3, 405(1938).
- (21) Kharasch, Legault and Sprowls, ibid., 3, 409(1938).

Chloride

Cyanide

$\alpha$ -Furyl\*

p-Methoxyphenyl

o-Methoxyphenyl

$\alpha$ -Naphthyl

Mesityl,  $\alpha$ -Thienyl

o-Tolyl

p-Tolyl

m-Tolyl

p-Fluorophenyl

Phenyl

p-Chlorophenyl, p-Bromophenyl

o-Chlorophenyl, o-Bromophenyl

m-Fluorophenyl, m-Chlorophenyl, m-Bromophenyl

m-( $\alpha, \alpha, \alpha$ -Trifluoro)tolyl

2,4-Dichlorophenyl, 2,5-Dichlorophenyl

Methyl

Ethyl

n-Propyl

n-Butyl

n-Heptyl

iso-Amyl

iso-Butyl

Benzyl

Allyl

\* The position of the  $\alpha$ -furyl radical was determined by the cleavage of di-p-methoxyphenyldi- $\alpha$ -furyllead (Gilman and Towne, J. Am. Chem. Soc., 61, 739(1939)).

$\beta$ -Phenylethyl

p-Chlorobenzyl, m-Chlorobenzyl, o-Chlorobenzyl

tert-Butyl

Diphenylmethyl

Triphenylmethyl

.

Sodyl (Na)

The series, indeed, had even further possibilities. Kharasch felt, as did Wöhler, that organic chemistry was a maze of isolated facts and a veritable forest of inconsistencies. Many of the rules presented previously, e.g., Kolbe's rule concerning the oxidation of alcohols, developed new exceptions as additions were made to the general store of experimental knowledge. It appeared possible that this series might be used as the basis of a new theory in organic chemistry which would prove to have very few exceptions. Thus, Kharasch was able to correlate this series with data concerning reactions of alcohols, acids, and the olefinic double bond. This same series made more logical heterogeneous data on the heats of combustion of organic compounds and it found a parallelism in the degree of dissociation of substituted ethanes into free radicals. In addition it enabled one to predict with some accuracy which radicals would be cleaved preferentially from an organometallic compound by halogen

acids and cleavage by acid is one of the most common of all the reactions undergone by organometallic compounds. It helped also to correlate the thermal stabilities of organometallic compounds.

It is not the purpose of this thesis to enter into the polemic which has waged over the merits of this series of radicals. Briefly, however, it is necessary to note several agreements and disagreements which have been reported.

The reaction itself has been criticized by Adkins(22) on the basis that no equilibrium exists between the products, and the amounts of the products are not a measure of the electronegativity of R and R<sup>\*</sup> but merely an indication of the relative rates of two competitive reactions. Furthermore, he contends that the designation of the term "electronegativity" to a radical is without physical foundation and this property of the radical, until it is established as real, cannot be assumed as the decisive factor in determining the ratio of the products obtained. Kharasch, Reimuth and Mayo(18) have answered that an equilibrium



does exist but that when R is considerably more electronegative than R<sup>\*</sup>, the concentration of RHg<sup>+</sup> and R<sup>\*</sup>- is so small as to be negligible. That the equilibrium is real finds basis in the slow disproportionation of an unsymmetrical mercurial into its two symmetrical forms. Thus, it is possible (22) Adkins, J. Chem. Education, 9, 1865(1932).

to correlate relative electronegativities with ionization rates. This rebuttal by Kharasch, Reinmuth and Mayo is largely discounted by the recent work of Calingaert and co-workers(12) who found that unsymmetrical mercurials when pure do not show any tendency to disproportionate and this is true also with unsymmetrical bismuth compounds. It is not possible then to correlate electronegativity with ionization rates. An equilibrium between the unsymmetrical compound and its two symmetrical forms is entirely possible and probably exists, but it is not certain that ionization occurs as Kharasch, Reinmuth and Mayo have shown above.

Wooster and Mitchell(23) have criticized the value of the series in predicting reactions. They found that diphenylmethane and triphenylmethane reacted with potassium or potassium amide in liquid ammonia whereas phenylmethane(toluene), phenylmethylethane(ethylbenzene) and phenylbenzylmethane(bibenzyl) did not. This could not have been predicted from the series. Kharasch and Reinmuth(16) have replied that these authors did not investigate the acidic character of the phenylated methanes by a conventional method and they cannot arbitrarily assume that triphenylmethane actually ionizes into  $(C_6H_5)_3C^-$  and  $H^+$  ions. Furthermore, the reaction with potassium in liquid ammonia may be described more plausibly as a molecular reduction.

(23) Wooster and Mitchell, J. Am. Chem. Soc., 52, 688(1930).

In this latter reply, Kharasch and Reimuth are greatly concerned with proving that the reactions of Wooster and Mitchell are not exceptions to the Kharasch Series but are unrelated reactions. In this way they maintain their original thesis, which is to develop theories in organic chemistry which would not tend to develop more and more exceptions as additions were made to the general store of experimental knowledge. But, if, in order to rule out exceptions it is necessary to invent such terms as "ability to receive an electron" the whole purpose of the theory is destroyed--that is, to enable one to simplify, correlate, and predict organic reactions. A wiser course would have been to allow the experimental data of Wooster and Mitchell as exceptions to the theory which by and large has a great usefulness.

This becomes clearer as additional exceptions to the Kharasch Series are reported. Rasuvayev and Koton(24) have obtained a different series of radicals by determining the ease with which different  $R_2Hg$  compounds undergo palladium catalyzed pyrolysis into free mercury and  $R\cdot R$ . The gross discrepancies between this series and the Kharasch Series make impossible a logical explanation.

Benzyl>Phenyl>p-Methoxyphenyl>p-Ethoxyphenyl>p-Bromophenyl>  
p-Tolyl> $\delta$ -Naphthyl

Austin(25) and Gilman, Towne and Jones(26) have found that

- (24) Rasuvayev and Koton, Ber., 66, 1210(1933).  
(25) Austin, J. Am. Chem. Soc., 53, 3514(1931).  
(26) Gilman, Towne and Jones, ibid., 55, 4689(1933).

the allyl and styryl radicals occupy anomalous positions above the phenyl radical in the acid cleavage of unsymmetrical lead compounds. Kharasch and Swartz(20) have argued that the hydrogen chloride adds to the double bond of the allyl group prior to cleavage but this does not alter the fact that an aliphatic chloropropyl group was cleaved before an aryl or phenyl group. Kharasch and Swartz cleaved allylphenylmercury with hydrogen chloride and recovered only 50% of the available mercury as phenylmercuric chloride. The remainder of the mercury was recovered as mercuric chloride and not as allylmercuric chloride. The formation of mercuric chloride was explained readily by the observation that allylmercuric chloride was cleaved by hydrogen chloride to give mercuric chloride and propylene. Under these same conditions the saturated aliphatic organomercuric chlorides are not cleaved by hydrogen chloride. Their mechanism involved the addition of a proton to the terminal carbon atom of the allylphenylmercury and cleavage into propylene and phenylmercuric chloride.



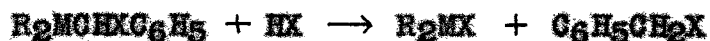
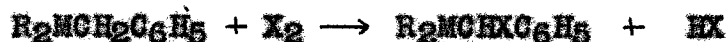
Since only 50% of the phenylmercuric chloride was formed it would appear that only half of the allylphenylmercury was cleaved according to the reaction above. The remaining allylphenylmercury was cleaved in the normal manner to give allylmercuric chloride. The allylmercuric chloride was then cleaved further to propylene and mercuric chloride. These authors

conclude that the hydrogen chloride cleavage of unsymmetrical organomercury compounds of the type  $\text{RHgCH}_2\text{CH}=\text{CH}_2$  is not a valid method for comparing the electronegativities of the radicals in question.

Koton and Florinskii(27) studied the rate of cleavage of  $\text{RHgX}$  by  $\text{ROH}$  with the formation of hydrocarbons and obtained the following series of radicals: phenyl > n-butyl > ethyl > n-propyl >  $\alpha$ -naphthyl. Challenger and Allpress(5, 6) and Stilp(8) have noted that the  $\alpha$ -naphthyl group is held more firmly by bismuth than is the phenyl group in cleavage of  $\text{R}_3\text{Bi}$  compounds by halogens. Challenger and Ridgway(28) have observed that the  $\alpha$ -naphthyl radical has a greater affinity for mercury than has the phenyl or tolyl radicals(see p. 36). Bullard(29), Kipping and Smith(30), Kraus and Bullard(31) and Kipping(32) have found that the benzyl radical is cleaved before methyl, ethyl, or propyl radicals when unsymmetrical tin compounds are cleaved by halogens. Bullard(33) cleaved dimethyldiethyltin with hydrogen chloride and obtained methyl-ethyltin dichloride. Diethyldi-n-propyltin and hydrogen chloride gave ethyl-n-propyltin dichloride.

- (28) Challenger and Ridgway, J. Chem. Soc., 121, 104(1922).
- (29) Bullard, J. Am. Chem. Soc., 51, 3065(1929).
- (30) Kipping and Smith, J. Chem. Soc., 101, 2552(1912).
- (31) Kraus and Bullard, J. Am. Chem. Soc., 48, 2135(1926).
- (32) Kipping, J. Chem. Soc., 1928, 2365.
- (33) Bullard, J. Am. Chem. Soc., 53, 3150(1931).

Kharasch and Flenner(17) have argued that the cleavage of the benzyl radical by halogens may not be simply a direct cleavage,  $R_2MCH_2C_6H_5 + X_2 \rightarrow R_2MX + C_6H_5CH_2X$ , but may go step-wise as follows:



The substitution of a hydrogen by halogen changes the "electronegativity" of the benzyl radical and it is not the benzyl group which is being cleaved.

A possible source of confirmation for this argument lies in the work of Kipping(32). Ethyltribenzyltin and iodine gave exclusive cleavage of the benzyl group while the hydrogen chloride cleavage of the same compound showed that the ethyl group was cleaved preferentially. It is evident that the series of radicals obtained by the cleavage of tin compounds by halogens does not coincide entirely with the series obtained by the acid cleavage of the same compounds.

On the other hand, the work of Kharasch and Sher(34) with the cleavage of organotin compounds and Simons(35) with germanium compounds gave a series of radicals identical with that of Kharasch. In addition, on the basis of the yields

(34) Kharasch and Sher, Unpublished studies. See reference 17.

(35) Simons, J. Am. Chem. Soc., 57, 1299(1935).

of  $R_2SnX_2$  or RH obtained in the following reactions:



Nesmeyanov and Kocheshkov(36) have obtained a series of radicals which agreed with the Kharasch Series.

Kharasch and Pines(37) have answered some criticism of the scission reaction by varying temperature, concentration, solvent, and hydrolytic agent and have found no change in the order of the radicals within the limits of the experiments carried out. Since phenylethylmercury cleaved instantly to yield benzene and ethylmercuric chloride, even though the latter compound is more soluble than phenylmercuric chloride, the solubility factor does not influence the reaction as was proposed by Wooster and Mitchell(23).

#### The Preferential Cleaving of Radicals from Bismuth in Unsymmetrical Organobismuth Compounds.

A reaction which appeared to possess some possibilities for determining the relative labilities of radicals attached to bismuth was the metal-metal interconversion between organobismuth compounds and n-butyllithium(38).

- (36) Nesmeyanov and Kocheshkov, Ucheniye Zapiski(Miss. Ber. Moskau Staats-Univ., 3, 283(1934) /Chem. Zentr., 1935, II, 3993/. See, also, Bobashinskaya and Kocheshkov, J. Gen. Chem.(U.S.S.R.) 8, 1850(1938) /C.A., 33, 5820(1939)/.
- (37) Kharasch and Pines, Unpublished studies, See reference 17.
- (38) Gilman, Yablunsky and Svigoon, J. Am. Chem. Soc., 61, 1170(1939).



This reaction probably takes place step-wise with the intermediate formation of unsymmetrical blumuth compounds. The choice of this particular reaction was not haphazard since it embodied several desirable features.

1. It appears to be an equilibrium reaction.
2. It is a reaction which in diethyl ether definitely measures the rate of metal-metal interchange. No side reactions such as hydrogen-metal or halogen-metal interchange have ever taken place even over prolonged periods of time.
3. Carbonation of the aryllithium compound formed gives good yields of the corresponding acid and the acid is readily identified.
4. The rate of metal-metal interchange is so rapid that within ten minutes and with only one equivalent of  $\underline{\text{m}}$ -butyllithium the yield of acid may reach 40% of the theoretical.
5. When two acids are obtained, it is possible to determine the amount of each acid present by fractional crystallization or by the neutralization equivalent of the mixture.

Of these five features, 1 and 2 are exceedingly important in view of Adkins' criticism (p. 95) of the Kharsach Series.

It was thought that a reaction between one equivalent of n-butyllithium and an unsymmetrical organobismuth compound,  $R_2R^1Bi$ , if run for a short time, might give a preferential replacement of the more labile radical (39). Thus, with di-p-chlorophenyl-o-tolylbismuth the following reaction was expected:



Carbonation, then, should have yielded o-toluic acid. The compound actually obtained was pure p-chlorobenzoic acid in 42.2% yield. This was entirely unexpected and several other unsymmetrical compounds containing the p-chlorophenyl radical were tested. Under similar conditions di-p-chlorophenyl- $\alpha$ -naphthylbismuth gave a mixture of acids which was shown to be 48.3% p-chlorobenzoic acid and 51.7%  $\alpha$ -naphthoic acid. From di-p-tolyl-p-chlorophenylbismuth there was obtained 17% p-toluic acid and 83% p-chlorobenzoic acid, while from diphenyl-p-chlorophenylbismuth the mixture was 24.5% benzoic

(39) It may appear that the ratio of  $2R:R^1$  in an  $R_2R^1Bi$  compound is unfavorable to  $R^1$  in the determination of the preferential cleavage of either  $R$  or  $R^1$ . If the ratio of the two radicals was the sole consideration the law of probability would certainly indicate that more  $R$  groups would cleave than would  $R^1$ . Yet, this is not confirmed by the experimental data. Diphenyl- $\alpha$ -naphthylbismuth gave principally cleavage of the  $\alpha$ -naphthyl radical, even though there were two phenyl groups available for each  $\alpha$ -naphthyl group. In diphenyl-p-chlorophenylbismuth, the p-chlorophenyl radical was cleaved in preference to the phenyl radical, though this radical is less available for reaction. Numerous similar examples will be found in the discussion which shows that the cleavage of a radical by n-butyllithium is determined by the nature of the radical, the solubility of the organometallic compound contain-

acid and 75.5% p-chlorobenzoic acid. The metal-metal inter-conversion reaction thus gave the p-chlorophenyl radical a lability equal to that of the d-naphthyl radical and above that of the p-tolyl, o-tolyl, and phenyl radicals. It was shown eventually that the p-chlorophenyl radical in organo-lead and organomercury compounds was cleaved in preference to the phenyl radical when treated with n-butyllithium(40). Triphenyl-p-chlorophenyllead and n-butyllithium gave a mixture of acids, 76% p-chlorobenzoic and 24% benzoic acid. From diphenyldi-p-chlorophenyllead there was obtained 98% p-chlorobenzoic acid and 2% benzoic acid. Phenyl-p-chlorophenylmercury gave 93.4% p-chlorobenzoic acid and 6.6% benzoic acid(see p. 109).

The anomalous behavior of the p-chlorophenyl radical in this present work is unquestionably an exception to the Kharasch Series. This statement is made unconditionally because when the o-chlorophenyl radical was tested it behaved normally, that is to say, it was not cleaved from bismuth under conditions which gave 48% cleavage with the p-chlorophenyl radical. This would give the o-chlorophenyl group a position similar to that assigned it by Kharasch,

ing the radical, the solvent, and probably temperature, to a slight extent. In a paraphrase, it is the quality and not the quantity of the radical which is a vital factor in this reaction.

(40) Studies with organolead compounds are by Mr. Fred Moore.

pines and Levine(19). Furthermore, when unsymmetrical bismuth compounds which do not contain the p-chlorophenyl group were reacted with n-butyllithium the expected products were obtained. Thus, diphenyl- $\delta$ -naphthylbismuth yielded 92.7%  $\delta$ -naphthoic acid and 7.3% benzoic acid, and di-p-tolyl- $\delta$ -naphthylbismuth gave pure  $\delta$ -naphthoic acid and no p-toluic acid. The  $\delta$ -naphthyl radical cleaved before either the phenyl or p-tolyl radicals but another anomalous behavior becomes evident, namely that the phenyl radical appeared to cleave more readily than the p-tolyl radical. This had been noted before in comparing the yields of benzoic acid and p-toluic acid obtained from diphenyl-p-chlorophenylbismuth and di-p-tolyl-p-chlorophenylbismuth, respectively(see p. 103). Incidentally, Challenger and Allpress(41) first demonstrated preferential cleavage of radicals in unsymmetrical bismuth compounds when they showed that diphenyl- $\delta$ -naphthylbismuth and iodine bromide yielded  $\delta$ -dionaphthalene and diphenylbismuth bromide.

There was no reason why this study had to be limited to unsymmetrical organometallic compounds. The extraordinary lability of the p-chlorophenyl radical in tetra-p-chlorophenyltin was demonstrated by Mr. Fred Moore in these laboratories. Tetraphenyltin in benzene-petroleum ether underwent about 5% metal-metal interchange with n-butyllithium. In these (41) Challenger and Allpress, J. Chem. Soc., 107, 16(1915).

same solvents, tetra-p-chlorophenyltin reacted to the extent of 19%. It should be emphasized that these solvents strongly inhibit metal-metal interconversion.

In diethyl ether, under corresponding conditions, with one equivalent of n-butyllithium, followed by carbonation after ten minutes, tri-p-chlorophenylbismuth gave 49.6% p-chlorobenzoic acid; tri-p-bromophenylbismuth, 41.3% p-bromobenzoic acid; tri-p-fluorophenylbismuth, 41.4% p-fluorobenzoic acid; triphenylbismuth, 5.8% benzoic acid; tri-p-tolylbismuth, 2.2% p-toluic acid; tri-p-ethoxyphenylbismuth, 2% p-ethoxybenzoic acid; and tri-o-tolylbismuth, no o-toluic acid. Trimesitylbismuth behaved anomalously, also, since it underwent no metal-metal interchange with n-butyllithium under these conditions. With tri- $\alpha$ -naphthylbismuth, the yield of corresponding acid was 1.2%. Here, however, the insolubility of the bismuth compound became a factor in the reaction. In all the reactions described above, the bismuth compounds were completely dissolved in the solvent prior to the addition of the n-butyllithium. Tri- $\alpha$ -naphthylbismuth is practically insoluble in diethyl ether and the slow rate of reaction is due probably to this since with the ether-soluble unsymmetrical bismuth compounds containing the  $\alpha$ -naphthyl radical it showed itself to have a lability equal to that of the p-chlorophenyl radical(p. 103). The use of a benzene-ether mixture in which tri- $\alpha$ -naphthylbismuth is sol-

uble decreased the yield of *o*-naphthoic acid to 0.6%. This was to be expected because benzene inhibits metal-metal interconversion(see Discussion).

In benzene-petroleum ether mixtures, tri-*p*-chlorophenylbismuth and di-*p*-chlorophenyl-*o*-tolylbismuth did not undergo metal-metal interchange with *n*-butyllithium.

Furthermore, in the reactions between *n*-butyllithium and di-*p*-tolylmercury or di-*p*-chlorophenylmercury, if the volume of solvent(diethyl ether) was increased, there was a corresponding increase in metal-metal interconversion. These two mercurials are rather insoluble in ether. Thus, a suspension of di-*p*-tolylmercury in 40 ml. of ether and one equivalent of *n*-butyllithium, followed by carbonation after ten minutes, gave 28.2% *p*-toluic acid and 51% of the mercurial was recovered unreacted. A suspension of di-*p*-chlorophenylmercury, treated identically, gave 51.1% *p*-chlorobenzoic acid and 41% of the mercury compound was recovered. Neither mercury compound was completely soluble in 60 ml. of ether, yet, with the former compound the yield of *p*-toluic acid was 41.5% while 33.4% of the unreacted mercurial was recovered, and with the latter compound, the yield of *p*-chlorobenzoic acid was 67.8% and only 28.3% of the di-*p*-chlorophenylmercury was recovered. In these last two experiments the conditions were identical with those under which the first two experiments were carried out except for the

increase in volume of the solvent. From a reaction between diphenylmercury and n-butyllithium carried out in 40 ml. of ether (in which the mercurial was completely soluble) there was obtained, subsequent to carbonation after ten minutes, a 29.4% yield of benzoic acid. This would have placed the phenyl radical equal to the p-tolyl radical in lability, if only one experiment had been carried out with di-p-tolylmercury. A second reaction showed how incorrect such an assumption would have been. In the experiments using 60 ml. of ether more of the mercurial dissolved and was, therefore, able to react with the n-butyllithium to a greater extent than when the reaction was carried out in 40 ml. of ether.

Dimesitylmercury and n-butyllithium, carbonated after ten minutes interaction, gave 72.5% cleavage. This is in marked contrast to the reaction with trimesitylbismuth and n-butyllithium which gave no cleavage under corresponding conditions.

All the metal-metal interchange reactions carried out in this study are summarized in Table I.

Incidental to this study, phenyl-p-chlorophenylmercury has been prepared in 80.3% yield by the reaction between phenylboric acid and p-chlorophenylmercuric chloride in the presence of alkali according to the method of Friedlina, Nesmeyanov and Kocheshkov(42). These authors did not prepare (42) Friedlina, Nesmeyanov and Kocheshkov, Ber., 68, 565(1935).

this compound. Kharasch and Flenner(17) prepared phenyl-*p*-chlorophenylmercury from  $C_6H_5HgX$  and  $p-ClC_6H_4HgBr$  and from  $p-ClC_6H_4HgX$  and  $C_6H_5HgBr$ , and reported that the product in either case melted at 190-210°. They did not recrystallize the compound. Kharasch, Pines and Levine(19) prepared the same compound later by essentially the same methods and reported a melting point of 165-205°. The crude product prepared by the method described above melted at 120-165°, and progressive crystallizations from benzene-petroleum ether gave melting points of 190-210°, and 220-227°. One crystallization of the crude product from chloroform-ethanol gave a colorless product melting at 190-215°. Metal-metal interconversions were carried out with three different products: (1) the crude product, (2) the compound obtained after two crystallizations from benzene-petroleum ether(m. p., 220-227°), and (3) the chloroform-ethanol crystallization product. The yields of acid obtained after reaction in the usual way with *n*-butyllithium followed by carbonation after ten minutes were from (1) 93.8% *p*-chlorobenzoic acid, 6.2% benzoic acid; from (2) 91% *p*-chlorobenzoic acid, 9.0% benzoic acid; and from (3) 95.5% *p*-chlorobenzoic acid, 4.5% benzoic acid. It would appear that no marked changes are occurring in the recrystallization of the unsymmetrical mercurial even though the melting points would indicate a slowly increasing concentration of the higher melting di-*p*-chlorophenylmercury (m. p., 243-4°).

Di-p-chlorophenylmercury was prepared in 80.4% yield by conversion of p-chlorophenylmercuric chloride with hydrazine(43). This compares well with the 81% yield reported by Hein and Wagler(44) who used copper and pyridine as the conversion agent.

- (43) Gilman and Barnett, Rec. trav. chim., 55, 563(1936).  
(44) Hein and Wagler, Ber., 58, 1499(1925).

# EXPERIMENTAL

A few typical metal-metal interchange reactions will be described in detail. The results are summarized in Table I.

Reaction Between Di-p-chlorophenyl-o-tolylbismuth and n-Butyllithium. Two and sixty-two hundredths grams (0.005 mole) di-p-chlorophenyl-o-tolylbismuth in 45 ml. of ether were treated with 0.005 mole n-butyllithium. The total volume was 65 ml. After stirring at room temperature for ten minutes the reaction mixture was poured on crushed dry ice, and allowed to stand for about a day to allow the butylbismuth compound formed to oxidize(37). The mixture was extracted thoroughly with 25 ml. of 10% potassium hydroxide solution. The alkaline extract was boiled with a little Norit and filtered. Acidification of the clear filtrate gave 0.33 g. acid. m. p., 233-4°. A mixed m. p. with p-chlorobenzoic acid was 234-5°. The yield of acid was 42.2%. The aqueous filtrate from the chlorobenzoic acid was extracted with ether, the ether extracts were dried, and distilled. The residue which would not distill from the water bath, was subjected to vacuum distillation at 15 mm. and heated by an external bath at 100-110°. Some valeric acid distilled, but no residue of o-toluic acid remained in the flask.

From the original ether layer there was recovered 0.85 g. (32.4%) of unreacted di-p-chlorophenyl-o-tolylbismuth,

m. p.,  $103.5^{\circ}$  and the mixed m. p. with an authentic sample of the bismuth compound was  $103.5^{\circ}$ .

If the recovered unreacted bismuth compound is considered the yield of *p*-chlorobenzoic acid was 62.4%.

Reaction Between Diphenyl- $\alpha$ -naphthylbismuth and *n*-Butyllithium. To a solution of 1.23 g. (0.0025 mole) diphenyl- $\alpha$ -naphthylbismuth in 40 ml. of ether was added 0.0025 mole *n*-butyllithium and after ten minutes stirring the mixture was carbonated. Worked up in the manner described above there was obtained 0.095 g. of acidic material insoluble in water. Without purification, this crude product melted at  $158-9^{\circ}$  and a mixed m. p. with  $\alpha$ -naphthoic acid was  $158-9^{\circ}$ . The yield was 21.6%. By exhaustive extraction of the aqueous filtrate from the  $\alpha$ -naphthoic acid there was obtained 0.005 g. (1.7%) benzoic acid, m. p.,  $119-20^{\circ}$ , and mixed m. p.,  $120^{\circ}$ . The recovery of unreacted bismuth compound was 0.48 g. (39%).

Preparation of Di-*p*-chlorophenylmercury. The complex,  $p\text{-ClC}_6\text{H}_4\text{N}_2\text{Cl}\cdot\text{HgCl}_2$ , was prepared according to the directions of Nesmeyanov(45) and decomposed by adding slowly to a suspension of copper bronze in acetone at  $0^{\circ}$ . After allowing the mixture to stand for a day, the acetone was evaporated and the residual solid thoroughly extracted with chloroform in a Soxhlet extractor. The chloroform was then distilled (45) Nesmeyanov, Ber., 62, 1010(1929).

to give a 69.2% yield of p-chlorophenylmercuric chloride. Nesmeyanov(45) reported a 46% yield.

DL-p-chlorophenylmercury was obtained in 80.4% yield by treatment of the p-chlorophenylmercuric chloride with hydrazine.

Preparation of Phenyl-p-chlorophenylmercury. To 3.47 g. (0.01 mole) p-chlorophenylmercuric chloride in 100 ml. of boiling 95% ethanol was added a mixture of 1.2 g. (0.01 mole) phenylboric acid in 20 ml. ethanol and 5 ml. of 20% sodium hydroxide, also at the boiling point. Reaction occurred instantly and the mixture, after cooling to room temperature, was diluted with 250 ml. of water and the mixture extracted with ether. The ether extract was washed with 10 ml. of 25% sodium hydroxide solution, then twice with water, and dried over calcium chloride. Evaporation of the ether gave 3.12 g. (80.2% yield) of phenyl-p-chlorophenylmercury, m. p., 190-215° after crystallization from chloroform-ethanol.

Reaction Between DL-p-chlorophenylmercury and n-Butyllithium. Two and twelve-hundredths grams (0.005 mole) dl-p-chlorophenylmercury in 40 ml. ether were treated with 0.005 mole of n-butyllithium with vigorous stirring. The reaction mixture first turned red and then faded to a pale pink after several minutes. The mixture was carbonated after ten minutes by pouring on crushed dry ice. The residue which remained in the reaction flask weighed 0.77 g. and was unreacted

di-p-chlorophenylmercury which had not dissolved. The carbonated mixture was extracted with 25 ml. of 10% potassium hydroxide solution, made slightly acid with hydrochloric acid, and then alkaline by the addition of solid sodium bicarbonate. The alkaline solution was filtered and the clear filtrate was acidified. The yield of acid was 0.4 g. (51.1%), m. p., 233-4° and a mixed m. p., with authentic p-chlorobenzoic acid, was 233-4°.

From the ether an additional 0.1 g. unreacted mercurial was recovered. The total recovery was 0.87 g. (41.4%).

If the recovered unreacted mercurial is considered, the yield of acid was 86.8%.

TABLE I

SUMMARY OF METAL-METAL INTERCONVERSION REACTIONS \*  
(Solvent, diethyl ether; Temp., 25°C.)

Compound	Time	Equiv.		Carboxylic Acids
		n-C <sub>4</sub> H <sub>9</sub> Li	n-C <sub>4</sub> H <sub>9</sub> Li	
(p-CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi	20 hrs.	3		70% p-toluic acid
"	1 hr.	3		17.7%, 20% "
"	10 min.	1		2.2%, trace "
(p-ClC <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi	18 hrs.	3		90% p-chlorobenzoic acid
"	10 min.	3		44.8%, 45.5% "
"	10 min.	1		44.7%, 48.6% "
(p-FC <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi	10 min.	1		40%, 42.8% p-fluorobenzoic acid
(p-BrC <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi	10 min.	1		41.8%, 40.8% p-bromobenzoic "
(o-ClC <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi	10 min.	1		No acid in two check experiments
(p-C <sub>2</sub> H <sub>5</sub> CO <sub>2</sub> C <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi	11 hrs. 10 min.	3 1		27.4% p-ethoxybenzoic acid 1.9%, 1.5% "
(o-C <sub>2</sub> H <sub>5</sub> CO <sub>2</sub> C <sub>6</sub> H <sub>4</sub> ) <sub>3</sub> Bi	11 hrs.	1		64% o-ethoxybenzoic acid

\* The data of Gilman, Yablunsky and Svigoon(37) are included for comparison purposes. The yields of acids are based on the amounts theoretically possible from the reaction, R<sub>3</sub>Bi + n-C<sub>4</sub>H<sub>9</sub>Li → R<sub>2</sub>Bi-n-C<sub>4</sub>H<sub>9</sub> + RLi → RCO<sub>2</sub>H. When an R<sub>2</sub>Bi compound gave RCO<sub>2</sub>H and R'CO<sub>2</sub>H, the yields again were calculated on the basis that either R or R' cleavage was the sole reaction. In the values given no allowance was made for recovered organometallic compound. This was necessary because with some of the bismuth compounds it was very difficult to recover the unreacted compound.

TABLE I (cont'd.)

$C_6H_5)_2B1$	10 min.	1	3.3%, 5.8% benzoic acid	No acid in two check experiments
$(C_6H_5)_2B1$	10 min.	1	48.1% $\alpha$ -naphthoic acid	1.3%
$(\alpha-C_{10}H_7)_2B1$	18 hrs.	3	21.6% $\alpha$ -naphthoic acid	1.7% benzoic acid
$(C_6H_5)_2(\alpha-C_{10}H_7)B1$	10 min.	1	6.97%, 5.2% $\alpha$ -naphthoic acid	No p-toluic acid
$(C_6H_5)_2(p-C_{10}H_7)B1$	10 min.	1	30.7%, 28.1% p-chlorobenzoic acid	3.4%, 10% benzoic acid
$(p-CH_3C_6H_4)_2(p-C_{10}H_7)B1$	10 min.	1	30.7%, 25.6% p-chlorobenzoic acid	7.3%, 8.0% p-toluic acid
$(p-CH_3C_6H_4)_2(\alpha-C_{10}H_7)B1$	10 min.	1	23.5%, 20.2% p-chlorobenzoic acid	22.9%, 22.4% $\alpha$ -naphthoic acid
$(p-CH_3C_6H_4)_2(p-CH_3C_6H_4)B1$	10 min.	1	42.2%, 34.5% p-chlorobenzoic acid	No p-toluic acid
$(2,4,6-(CH_3)_3C_6H_2)_2B1$	10 min.	1	No acid in two check experiments	
$(p-C_{10}H_7)_2B1$	10 min.	1	51.1% p-chlorobenzoic acid	(40 ml. of ether)
$(p-C_{10}H_7)_2B1$	10 min.	1	67.6% p-chlorobenzoic acid	(60 ml. of ether)

TABLE I (Cont'd.)

$(C_6H_5)_2Hg$	10 min.	1	29.4%, 22.8% benzoic acid
$C_6H_5HgC_6H_4Cl-p$	10 min.	1	57.5%, 50.9% p-chlorobenzoic acid 4.9%, 4.9% benzoic acid
$(p-CH_3C_6H_4)_2Hg$	10 min.	1	28.2% p-toluic acid (40 ml. of ether)
"	10 min.	1	41.5% p-toluic acid (60 ml. of ether)
$(2,4,6-(CH_3)_3C_6H_2)_2Hg$	10 min.	1	72.5% $\beta$ -isodurylic acid

## DISCUSSION OF RESULTS

The experimental data summarized in Table I demonstrate unequivocally the anomalous lability of the p-chlorophenyl, p-bromophenyl, and p-fluorophenyl radicals when attached to bismuth if displacement of the radical by n-butyllithium is used as a criterion. The p-chlorophenyl radical also possesses an unusual lability when attached to mercury, tin, and lead.

Recent studies by Kharasch, Pines and Levine(19) have shown that the p-fluorophenyl radical is somewhat more labile than the phenyl radical when attached to mercury. This was based on the relative ease of cleavage by hydrogen chloride of the unsymmetrical phenyl-p-fluorophenylmercury. These authors found also that the p-chlorophenyl, p-bromophenyl, o-bromophenyl, m-bromophenyl, and m-fluorophenyl radicals are somewhat less labile than the phenyl radical. It would appear, then, that the p-fluorophenyl radical is the only exception to the rule of Kharasch and Flenner(17) that direct substitution decreases the lability of the phenyl radical. Other experiments indicated that the m-(d,d,d-trifluoro)tolyl radical is cleaved less readily than the phenyl and m-chlorophenyl radicals. Thus, it becomes evident that substitution in the side chain decreases the lability of the tolyl radical. Also, the trifluoromethyl group in the m-position has a greater effect than a chlorine atom in the same position in decreasing the

lability of the phenyl radical. Furthermore, the o, m, and p-chlorobenzyl radicals are cleaved less readily than the unsubstituted benzyl radical.

Thus, the metal-metal interconversion reaction confirms not only the position of the p-fluorophenyl radical as an exception to the rule of Kharasch and Flenner, but establishes the p-chlorophenyl and p-bromophenyl radicals as exceptions to this rule also. The position of the p-chlorophenyl radical in the Kharasch Series is strengthened by the metal-metal interchange reaction which gives it a very low order of reactivity. Kharasch, Pines and Levine remark that the p-fluorophenyl radical possesses only a slightly greater lability than the phenyl radical. The metal-metal interconversion reaction demonstrates a decided difference in the ease with which a p-halogen-substituted-phenyl is cleaved as compared to the phenyl radical.

The metal-metal interconversions between symmetrical triarylbismuth compounds and butyllithium are of more than ordinary interest. First, they offer confirmation of the series of radicals obtained by the metal-metal interchange carried out with unsymmetrical bismuth compounds. This indicates that the cleavage of unsymmetrical compounds is not particularly unusual and it leads to the conclusion that a series of radicals need not of necessity be derived from the preferential replacement of one radical from a mixed organo-

metallic compound. Reactions between symmetrical organolead, -tin, and -mercury compounds and n-butyllithium confirm this, since a series of radicals obtained by the cleavage with butyllithium of unsymmetrical derivatives of these metals agrees well with a corresponding series obtained from the symmetrical compounds.

The p-chlorophenyl radical is a vinylog(46) of the o-chlorophenyl radical.



Thus, on theoretical grounds there should be a general similarity in the reactions of these two radicals. It is evident from what has been said before that there are marked differences in the ease with which these two groups are cleaved from metals in organometallic compounds. Hydrogen chloride cleaves 80% of the o-tolyl groups in p-tolyl-o-tolylmercury. The p-methoxyphenyl radical is cleaved exclusively from p-methoxyphenyl-o-methoxyphenylmercury by hydrogen chloride. On the basis of these reactions it does not appear possible to consider o- and p-substituted phenyls as vinylogs.

Experiments with triphenylbismuth, tri-p-tolylbismuth, diphenyl- $\alpha$ -naphthylbismuth, and di-p-tolyl- $\alpha$ -naphthylbismuth (46) Fuson, Chem. Rev., 16, 1(1935).

indicate that the phenyl radical is more labile than the p-tolyl radical. Mr. Fred Moore has shown that this is not true when these two radicals are attached to lead, since diphenyldi-p-tolyllead and n-butyllithium gave 79% p-toluic acid and 21% benzoic acid after carbonation. In our work it was shown that the p-tolyl group is more readily displaced than is the phenyl group when attached to mercury. It must be concluded from this that in developing a series of radicals based on cleavage from a metal account must be taken of the central atom of the organometallic compound.

It is necessary to call attention again to the important part which the solvent plays in all these metal-metal interchanges. In diethyl ether the reaction between organobismuth compounds and n-butyllithium may proceed to the extent of 50%, but in benzene-petroleum ether mixtures no observable interconversion occurs.

Mr. Reuben Jones in these laboratories found that in diethyl ether at 25° di-p-bromophenylmercury and n-butyllithium give 100% metal-metal interchange in three minutes. In petroleum ether (b.p., 28-30°), however, after twenty hours reflux there was only 70% interconversion. From tetraphenyllead and n-butyllithium in benzene-petroleum ether, after six hours of refluxing at 60°, Mr. Fred Moore obtained 69% interconversion. In diethyl ether, after seven hours, the same compounds had reacted to give 70% interconversion.

If benzene alone was used as the solvent no interconversion occurred even after refluxing for twenty-four hours. Tetraphenyltin and n-butyllithium in diethyl ether-benzene underwent 88% interconversion. In benzene, no interchange occurred.

Mr. Fred Moore has studied the effect of temperature on metal-metal interchange. He found that there was little difference in the extent of metal-metal interchange when the reaction between diphenylmercury and n-butyllithium was run at 25° or -80° C.

The solubility of the organometallic compound is another factor which has not been stressed before. The reactions with tri- $\alpha$ -naphthylbismuth, di-p-tolylmercury, and di-p-chlorophenylmercury bring this out very clearly. The bismuth compound did not react because of its extreme insolubility in diethyl ether. With the two mercury compounds which are not readily soluble in ether, an increase of this solvent gave a corresponding increase in reaction. This was due to the greater proportion of the mercurial which was in solution and available for interaction with butyllithium.

Based on metal-metal interconversion reactions between tertiary  $R_3Bi$  or  $R_2R'Bi$  compounds and n-butyllithium it is possible to evolve the following series of radicals in order of decreasing lability:

p-chlorophenyl, p-bromophenyl, p-fluorophenyl,  $\alpha$ -naphthyl  
phenyl

p-tolyl

p-ethoxyphenyl

o-tolyl, mesityl, o-chlorophenyl

The position of the  $\alpha$ -naphthyl radical is based on the reaction of di-p-chlorophenyl- $\alpha$ -naphthylbismuth and n-butyllithium.

In the Kharasch Series these radicals possess the following order of decreasing ease of cleavage from mercury:

mesityl

$\alpha$ -naphthyl

o-tolyl

p-tolyl

p-fluorophenyl

phenyl

p-chlorophenyl, p-bromophenyl

o-chlorophenyl

The p-ethoxyphenyl radical is not listed in this series but the p-methoxyphenyl radical is placed above the o-tolyl radical and approximately equal to the mesityl radical in lability. One may arbitrarily assume that the p-ethoxyphenyl group would occupy a position similar to the p-methoxyphenyl group.

The very slight metal-metal interchange between tri-p-ethoxyphenylbismuth and n-butyllithium is unexpected in view of the position given the p-ethoxyphenyl radical in the Kharasch Series, and at the present time there is no explanation for this. The absence of any observable reaction be-

tween trimesitylbismuth, tri-o-tolylbismuth, or tri-o-chlorophenylbismuth and n-butyllithium is also anomalous and indicates the possibility that steric hindrance may play an important role in this metal-metal interconversion reaction. This finds confirmation in the 72.5% cleavage of dimesitylmercury by n-butyllithium under the same conditions which gave no cleavage with trimesitylbismuth.

The two series given above differ considerably and are almost reversals of one another. The futility of trying to generalize any single series of radicals becomes evident. At this time it is unwise to say any more than that the series of radicals obtained by the metal-metal interconversion reactions with n-butyllithium is restricted in use to the reaction from which it was derived.

# SUMMARY

It has been shown that metal-metal interconversion reactions between  $R_3Bi$  and  $R_2R'Bi$  compounds and  $n$ -butyllithium



may be used as a measure of the ease with which R groups are displaced from bismuth. In a series of reactions with a large number of organobismuth compounds it was possible to give to various radicals or R groups positions of lability relative to the ease with which they were cleaved from the metal. Thus, the  $p$ -chlorophenyl,  $p$ -bromophenyl,  $p$ -fluorophenyl, and  $\alpha$ -naphthyl groups were cleaved most readily, then, with increasing difficulty, phenyl,  $p$ -tolyl, and  $p$ -ethoxyphenyl. Under the conditions employed in these reactions, the  $o$ -tolyl,  $o$ -chlorophenyl, and mesityl groups were not displaced from bismuth. This is almost a reversal of the Kharasch Series for these radicals. The unusual lability of the  $p$ -chlorophenyl radical has been demonstrated also when it is attached to lead, tin, and mercury. This behavior of the  $p$ -chlorophenyl radical is to be contrasted sharply with that of the  $o$ -chlorophenyl radical which is not cleaved from bismuth by  $n$ -butyllithium under the conditions which gave 48% cleavage with the former radical.

It has been emphasized, also, that the nature of the solvent, the solubility of the organometallic compound, and

the central metal of the organometallic molecule are factors which greatly influence the rate of metal-metal interchange. Steric effects may be an important factor also.