



Spring 2015

A New Synthesis of Bis (4-tert-butylphenyl) Iodonium Hexafluoroantimonate; a Known Catalyst for Photopolymerization

Matthew C. Salvi

Sacred Heart University, salvimatt@gmail.com

Follow this and additional works at: http://digitalcommons.sacredheart.edu/chem_thes

 Part of the [Polymer Chemistry Commons](#)

Recommended Citation

Salvi, Matthew C., "A New Synthesis of Bis (4-tert-butylphenyl) Iodonium Hexafluoroantimonate; a Known Catalyst for Photopolymerization" (2015). *Chemistry Master's Theses*. 11.
http://digitalcommons.sacredheart.edu/chem_thes/11

This Thesis is brought to you for free and open access by the Chemistry and Physics at DigitalCommons@SHU. It has been accepted for inclusion in Chemistry Master's Theses by an authorized administrator of DigitalCommons@SHU. For more information, please contact ferribyp@sacredheart.edu, lysobeyb@sacredheart.edu.

**A New Synthesis of Bis (4-*tert*-butylphenyl)
Iodonium Hexafluoroantimonate; a Known
Catalyst for Photopolymerization**

Matthew C. Salvi

Sacred Heart University

2015

**A New Synthesis of Bis (4-*tert*-butylphenyl) Iodonium
Hexafluoroantimonate; a Known Catalyst for Photopolymerization**

Master's Thesis

Submitted to the faculty

Sacred Heart University Chemistry Program

In Partial Fulfillment of
The Requirements for the Degree
Master of Chemistry

Matthew C. Salvi

2015

Sacred Heart University

Approval of the Master's Thesis

Name of Student: Matthew C. Salvi

Degree: Master of Science in Chemistry

Name of Thesis Advisor: Jeffrey H. Glans

Title of Thesis: A New Synthesis of Bis (4-*tert*-butylphenyl) Iodonium Hexafluoroantimonate; a Known Catalyst for Photopolymerization

The following persons have approved the work indicated above:

HRI Advisor Signature

Date

Thesis Advisor Signature

Date

Faculty Chairperson Signature

Date

Dean of Arts and Sciences Signature

Date

Permission to photocopy or microfilming of “A New Synthesis of Bis (4-*tert*-butylphenyl) Iodonium Hexafluoroantimonate; a Known Catalyst for Photopolymerization” for the purpose of individual scholarly constitution or reference is here by granted by the author. This permission is not to be interpreted as affecting publication of this work or otherwise placing it in the public domain, and the author reserves all rights of ownership guaranteed common law protection of unpublished manuscripts.

Matthew C. Salvi

Spring 2015

Acknowledgements

This paper has educated me in more ways than one but the bigger picture that I was able to gain clarity on was the process every chemist must go through when doing independent research. Chemistry is an experimental science in which most of your experimentation results in failure. The challenge is to keep your mind organized and your ideas fresh in order to continue on the path to an educated conclusion. Needless to say the entire process would not have been possible without the assistance of my advisors. I would like to first thank my thesis advisor Dr. Jeffrey Glans for taking the time out of his busy schedule to help guide me through this process. His enthusiasm and attention to detail drove me to think outside the box when facing an unforeseen challenge. I would also like to thank Kate Donahue, Steve Finson and the rest of the Hampford Research Inc. staff for supporting my efforts to attain higher education. Hampford's willingness to provide the facilities needed and the 30 years of chemical experience was invaluable. Finally, I would like to thank my family who has been involved in my development as a chemist and as an adult through every step of the way. They have been an endless source of strength, support and inspiration. They've encouraged me, stood up for me, challenged me, and set an example I hope to follow.

Abbreviations

BtPhI	Bis (4-tert-butylphenyl) Iodonium
MO	Molecular Orbital
DMP	Dess-Martin Periodinane
HOMO	Highest Occupied molecular orbital
PAG	Photo Acid Generator
UV	Ultraviolet
FTIR	Fourier transform infrared
amu	Atomic mass units

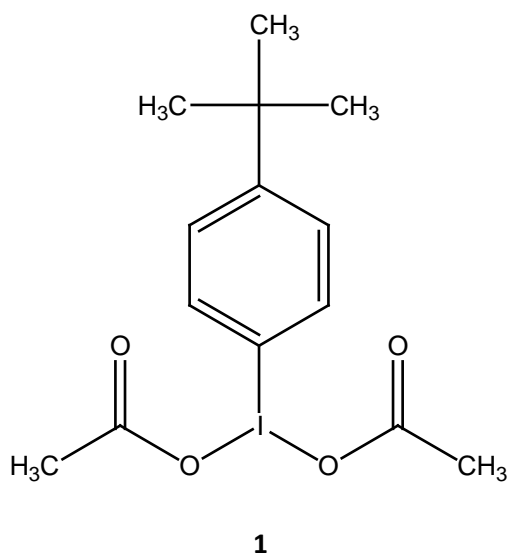
Table of Contents

Chapter 1 - Introduction.....	9
I. Hypervalent molecules	
II. λ^3 -Iodanes	
III. Aryliodonium compounds and their applications	
IV. Research Aim	
Chapter 2 – Results and Discussion	19
I. Attempted Synthesis of diacetoxy(<i>t</i> -butylphenyl)- λ^3 -iodane	
II. Synthesis of Bis (4- <i>tert</i> -butylphenyl)Iodonium hydrogen sulfate via Bis (acetyloxy)- λ^3 -iodanyl acetate	
III. FTIR Analysis: Reaction Product B	
IV. NMR Analysis : Reaction Product B	
V. Iodine Testing	
VI. FTIR Analysis: Bis (4- <i>tert</i> -butylphenyl) Iodonium Hexafluoroantimonate	
VII. NMR Analysis: Bis (4- <i>tert</i> -butylphenyl) Iodonium Hexafluoroantimonate	
VIII. Elemental Analysis: Bis (4- <i>tert</i> -butylphenyl) Iodonium Hexafluoroantimonate	
Chapter 3- Conclusions	29
Chapter 4 -Experimental Procedures.....	32
I. Attempted Synthesis of <i>t</i> -butyl (Diacetoxyiodo)benzene	
II. Synthesis of Bis (4- <i>tert</i> -butylphenyl) Iodonium hydrogen sulfate via Bis (acetyloxy)- λ^3 -iodanyl acetate	
III. Synthesis of Bis (4- <i>tert</i> -butylphenyl) iodonium hexafluoroantimonate	
Appendix	36
References	43

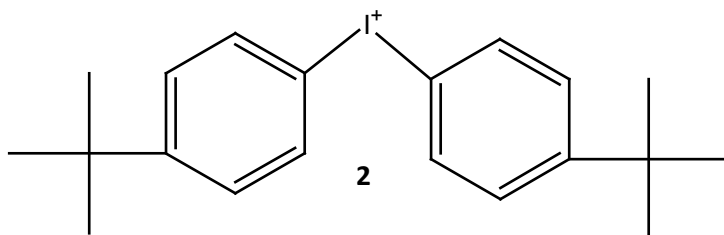
Abstract

This thesis describes a novel reaction protocol for the synthesis of bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate (**2**) via the formation of diacetoxy (*t*-butylphenyl)- λ^3 -iodane (**1**). It is also important to provide a safe and robust reaction procedure for future scaled-up production.

Diacetoxy (*tert*-butylphenyl)- λ^3 -iodane



Bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate

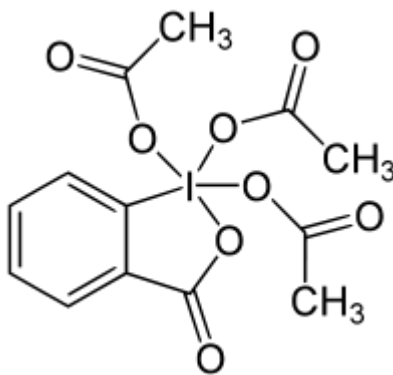


Chapter 1 – Introduction

I. Hypervalent Molecules

Over the last 20 years, organic hypervalent iodine compounds have emerged as versatile and environmentally benign reagents for various synthetically useful chemical transformations.¹ (Dichloro- λ^3 -iodanyl)benzene was first discovered in 1886 by German chemist Conrad Willgerodt but hypervalent iodine compounds received little attention until the 1983 synthesis of Dess-Martin Periodinane (DMP) (**3**).² This new compound quickly became an effective reagent for oxidizing primary alcohols to aldehydes and secondary alcohols to ketones under mild reaction conditions.² DMP helped revitalize organic chemists' interest about the untapped potential of hypervalent iodine compounds around the world.

Dess-Martin Periodinane



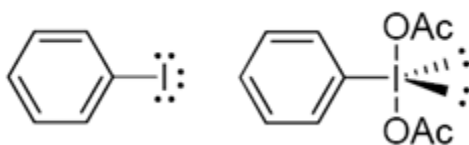
3

Iodine is the largest, most electropositive and most polarizable of the more common halogens.³ Due to these unique characteristics, iodine can exist in several stable hypervalent states.⁴ This is partially due to iodine's lower electronegativity value which more easily allows its electrons to distance themselves from the nucleus. Electronegative ligands therefore have a stabilizing effect on the molecule by withdrawing the electron density from the atom. This is believed to be due to its significantly larger

relative atomic mass (126.50 amu) than the elements above it in group 17, fluorine (19.99 amu), chlorine (35.45 amu) and bromine (79.90 amu).⁵

A hypervalent molecule describes a molecule that exceeds the octet rule and suggests that the bonding in hypervalent molecules is in some way different from that in “ordinary” molecules that obey the octet rule.⁶ These compounds are usually identified based on their oxidation state. For example, iodobenzene with an oxidation state of one is not hypervalent as it does not exceed the octet rule. On the other hand diacetoxy(phenyl)- λ^3 -iodane with 10 electrons is known as a hypervalent λ^3 -iodane and has an oxidation state of three which can be explained through a simple bonding model.

Figure 1. Octet rule versus Hypervalent: iodobenzene, diacetoxy (phenyl)- λ^3 -iodane



One widely accepted hypothesis is the 3 center-4 electron bonding model. This model considers the central halogen to be hypervalent which creates a linear system formed by three aligned closed-shell orbitals with 24 shell electrons and an overall charge of three. The problem is that this linear system has three molecular orbitals generated by the three p orbitals that should be fully occupied by six electrons.⁸ Resolution of the problem is achieved by the removal of two electrons from the antibonding MO creating a node in the highest occupied molecular orbital (HOMO). As a result, a higher concentration of the electron density is pushed towards the ligands. Iodine now becomes a soft electrophilic center that can be easily attacked by a number of different nucleophiles.⁷ Such a bond is highly polarized, longer and weaker compared to a regular covalent bond. The four electrons on the ligands plus the six electrons in the other three filled atomic orbitals equal a total of 10 electrons on the central iodine atom; this accounts for its description as a hypervalent species. (Figure 2)

Figure 2. Rundle-Pimentel molecular orbital model for electron-rich 3C-4e systems⁴

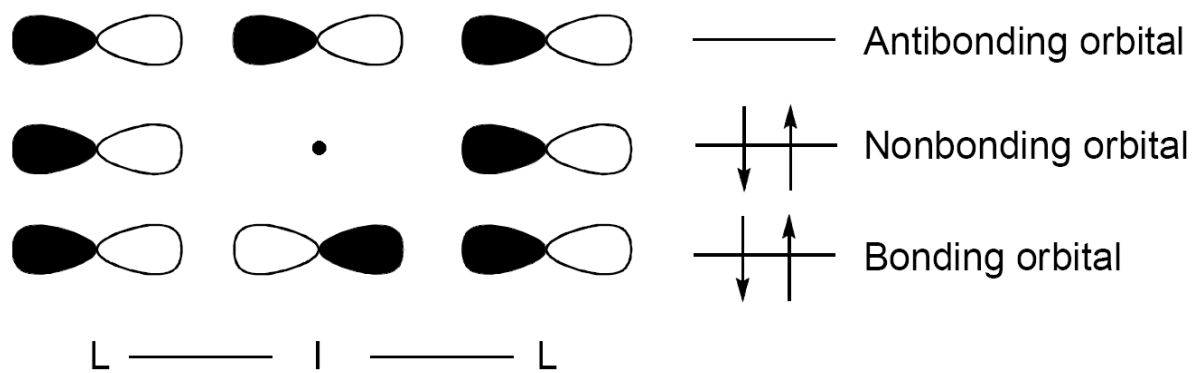
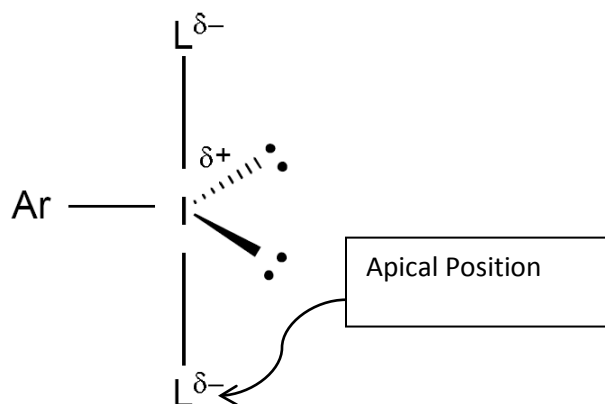
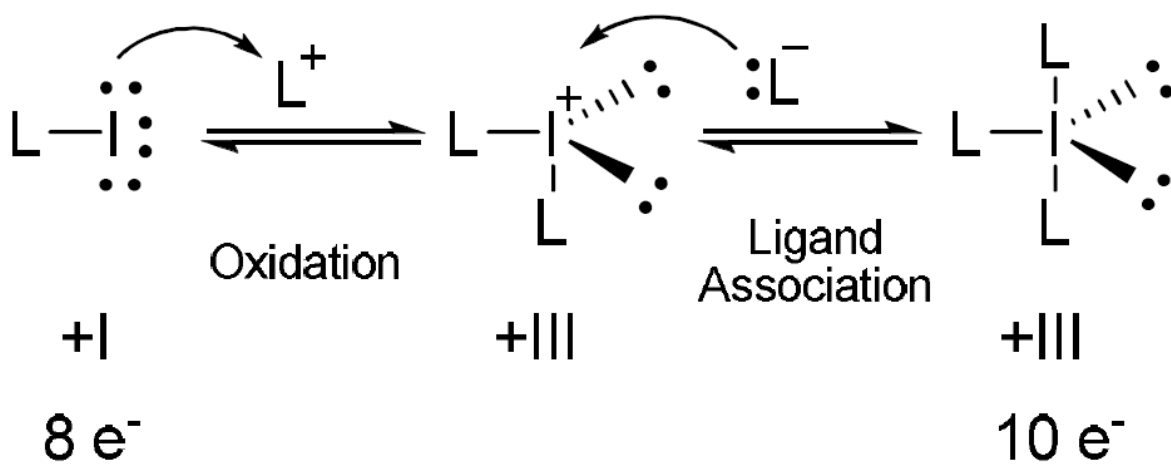


Figure 3. Geometry of λ^3 -iodanes⁴



The geometry of hypervalent λ^3 -iodanes is also unique in making them excellent nucleophilic reagents. The geometry is described as a distorted trigonal bipyramid with two heteroatom ligands occupying the axial positions and both electron pairs residing in equatorial positions.⁸ This can be more easily visualized as having a T-shape geometry based on the two ligands being perpendicular to the aryl-iodo bond. Bonding of the ligands uses the non-hybridized 5p orbital of iodine in the linear L-I-L bond. X-ray crystallography testing has confirmed that aryl- λ^3 -iodanes exhibit T-shaped geometry in the solid state.⁸ The oxidation reaction scheme shows the mechanism for oxidizing iodine with +I oxidation state to a hypervalent iodine +III compound (Figure 4).

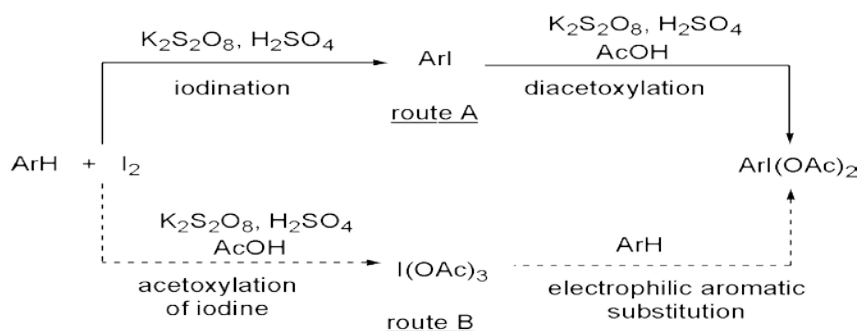
Figure 4. Oxidation of iodine compounds⁴



II. λ^3 -Iodanes

As mentioned earlier diacetoxy (phenyl)- λ^3 -iodane is a well-known crystalline compound within the (diacetoxyiodo) arene category. This compound is commonly used as a precursor for synthesizing diaryliodonium salts due to its reactivity and chemo selective characteristics.⁹ There are two reaction routes that lead to the generation of this molecule. The first route involves the iodination of an arene followed by the diacetoxylation to form the diacetoxy(phenyl)- λ^3 -iodane. The second route comprises the formation of bis (acetyloxy)- λ^3 -iodanyl acetate followed by an electrophilic aromatic substitution resulting in the diacetoxy(phenyl)- λ^3 -iodane product.⁹

Figure 5. Possible routes for generating diacetoxy(phenyl)- λ^3 -iodane⁹

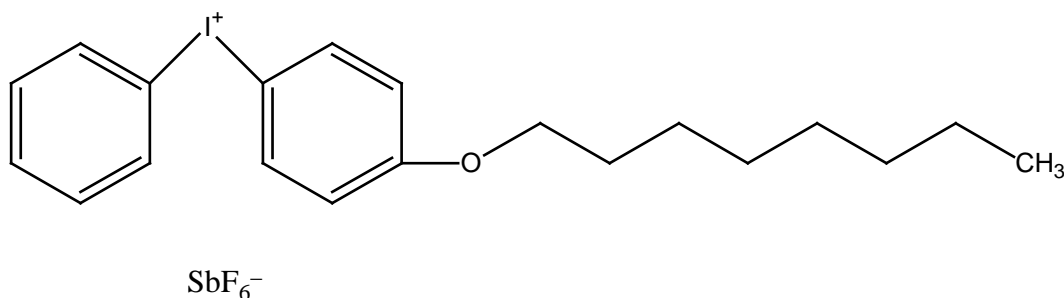


III. Aryliodonium compounds and their applications

Aryliodonium compounds such as diacetoxy(phenyl)- λ^3 -iodane represent an important class of hypervalent λ^3 -iodanes, particularly useful as reagents for arylation of various nucleophiles. This project will focus on aryl- λ^3 -iodanes which have similar chemical and reactivity properties as commonly used heavy metal reagents such as Hg(III), Ti(III), Pb(IV). Aryliodonium compounds are relatively non-toxic and have very few environmental issues. The heavy metal reagents on the other hand, have strict toxicity and environmental constraints. Aryl- λ^3 -iodane compounds also have mild synthetic reaction conditions and can be easily handled once synthesized due to their stability.⁹ Aryliodonium compounds are popular among organic chemists because of the fragile carbon-iodine bond it forms compared to other halogens like bromide or chlorine as discussed previously.

An aryliodonium compound's broad chemical utility include applications involving carbon-carbon bonds, carbon-heteroatom bonds, heteroatom-heteroatom bonds, oxidations, radical reactions and rearrangements.¹⁰ This has made this class of compound a valuable asset in organic chemistry. Stable aryliodonium compounds like bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate have found numerous practical applications; such as cationic photoinitiators based on photo acid generation (PAG) found in polymer chemistry.¹⁰ The majority of these applications involve coatings for both plastics and metals. For example, UV curable floor coatings have grown in popularity due to their non-toxic properties, increased longevity and speed of cure.¹¹ The floor coating formulation uses an aryliodonium photoinitiator combined with a resin to coat the desired area which is then cured with a UV light source. This provides a deep cure of the coating for enhanced durability enabling the customer to ensure a timely return to service.

Iodonium photoinitiators can also induce a variety of chain reactions in polymers, including cross-linking, catalytic deprotonation, and catalytic depolymerization. All of these reactions can be exploited in the design of printing resist materials.⁹ When formulated with the diaryliodonium salt photoinitiators, like 4-octyloxydiphenyliodonium hexafluoroantimonate (OPPI), epoxy resins undergo efficient cross-linking reactions to provide negative tone resists.¹¹



4

Process speed is always a topic of conversation in the photoresist production industry and arylidoniums provide an advantage for production through increased cure speed. Due to the molecule's weak carbon-iodine bond the radiolysis reaction doesn't have to work very hard to break that bond. The epoxy resin can then begin to polymerize. For example, in 1990 at General Electric Canada, Dr. James Crivello patented several compounds that reduced cure time to seconds using diaryliodonium salts. When using UV lamps with irradiation flux of 0.01 watts per square inch, effective polymerization was achieved within 1-20 seconds. As stated by Crivello a combination of heat and light may serve to reduce the overall cure time.¹⁵ By reducing the time a photoresist must be exposed to UV radiation the overhead cost and throughput capabilities are both improved.

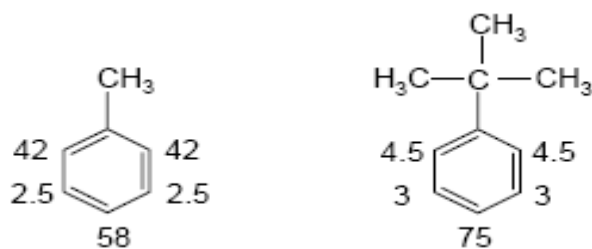
Research Aim

In this project reaction pathways to prepare the bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate will be discussed. Aryliodide compounds are available for purchase from most lab warehouses but are very expensive. In Hampford Research's case diacetoxy(phenyl)- λ^3 -iodane is the compound of interest that must be purchased from an outside source. In order to remove this price limiting material a procedure to form diacetoxy (*t*-butylphenyl)- λ^3 -iodane directly from *t*-butyl benzene and potassium iodide was desired.

To my knowledge there are no published syntheses that form bis (4-*tert*-butylphenyl) iodonium salts when starting solely with *t*-butyl benzene and potassium iodide. All current published syntheses start with an iodosubstituted benzene to form the diacetoxy (*t*-butylphenyl)- λ^3 -iodane product, where I will be attaching the iodine using potassium iodide.^{3,4}

t-Butyl benzene was selected because a substituent already present reduced the amount of reaction steps needed and can affect the regioselectivity of the reaction. The *tert*-butyl group, like all alkyl groups, is activating and ortho-para directing. This group's size crowds the ortho positions and decreases the rate of attack at those positions. A partial rate factor indicates how much the rate of substitution at a particular position is faster (or slower) than at a single position of benzene. This increased steric hindrance of the *tert*-butyl group makes each ortho position less reactive than para as can be seen in figure 6.

Figure 6. Partial rate factors for nitration of toluene vs *t*-butyl Benzene¹⁰

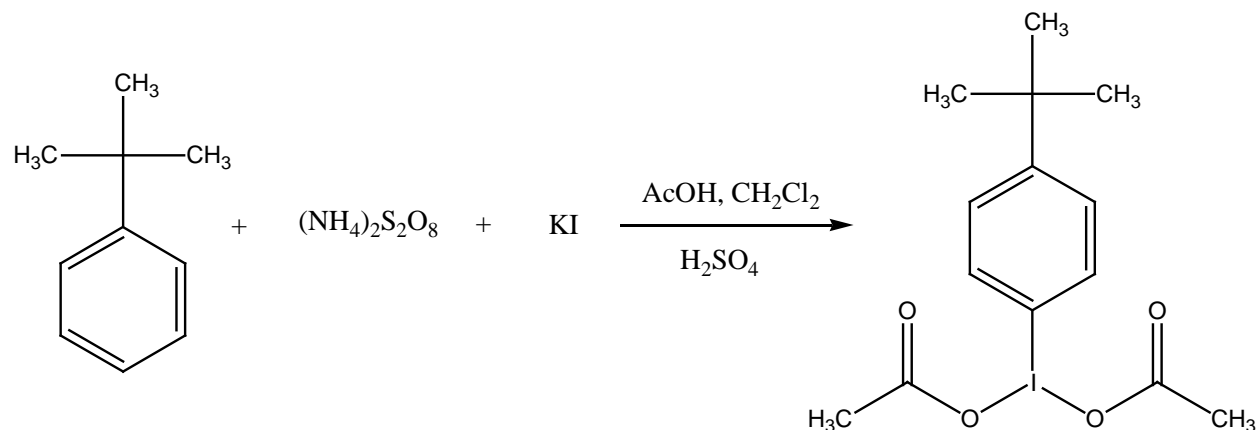


The regioselectivity of this reaction becomes important when looking at the purity of the iodobenzene intermediate. HRI's current iodobenzene precursor gives multiple side products when forming the diaryliodonium salt and leaves the product with a red color. A new high purity synthesis method would greatly improve the product's feasibility and value for future large scale production. It would also make HRI's process more financially sound by eliminating the need for an outside source of the precursor. With the ability to increase the amount of para-substituted iodobenzene product and decrease the amount of ortho/meta products there would in theory be a more homogenous composition of para-substituted iodobenzene intermediate. Increased purity of the intermediate product molecule would create a more efficient reaction when synthesizing the diaryliodonium salt. Increased purity of the final product is a crucial variable in making a diaryliodonium salt with good physical characteristics when used in curing applications.

Chapter 2 – Results & Discussion

I. Attempted Synthesis of diacetoxy(*t*-butylphenyl)- λ^3 -iodane

Scheme 1. Proposed one-pot synthesis of diacetoxy (*t*-butylphenyl)- λ^3 -iodane

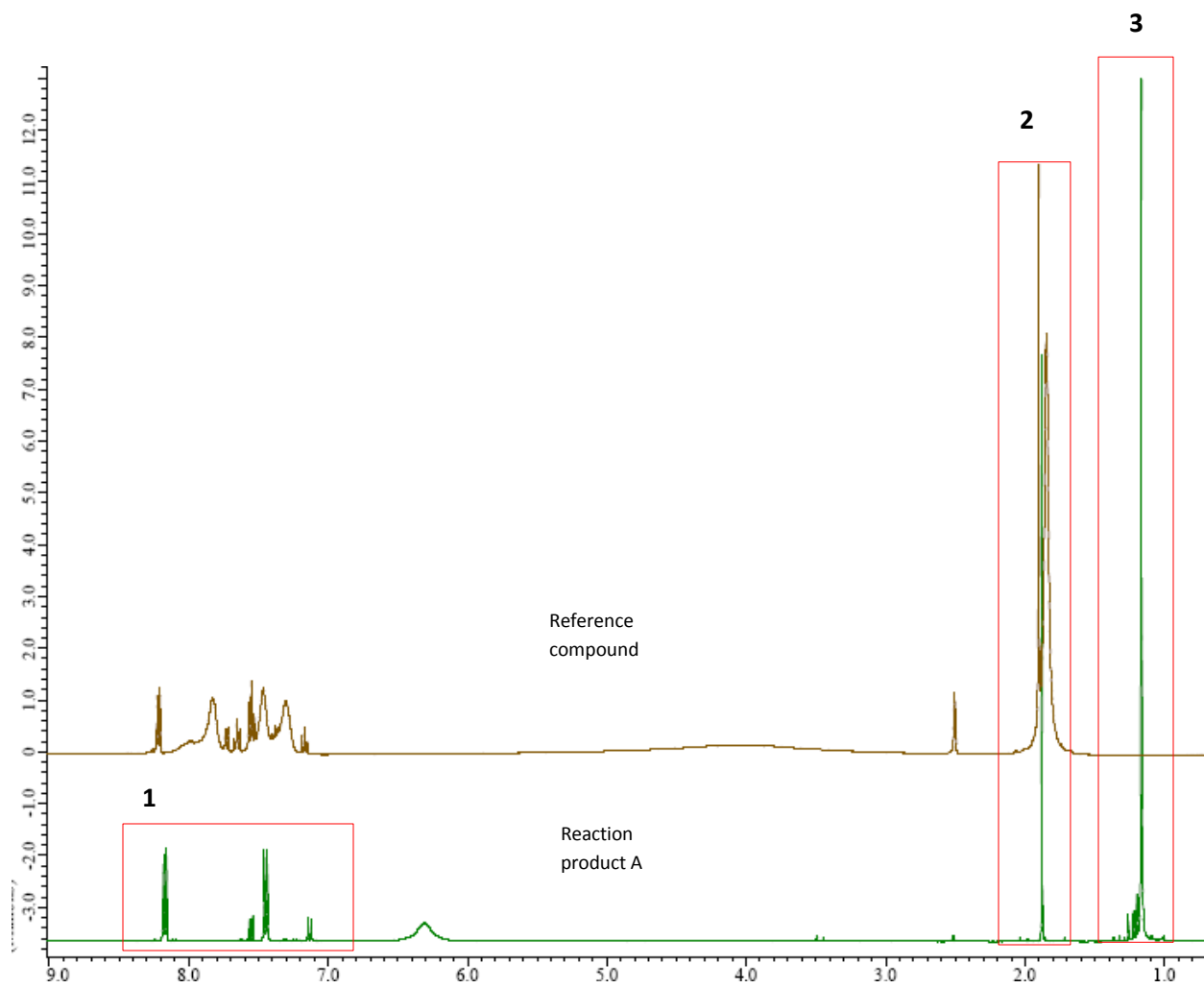


The attempted synthesis of diacetoxy (*t*-butylphenyl)- λ^3 -iodane gave a viscous brown oil as a product. The proton NMR spectra shows a doublet of doublets peaks signifying a para substituted aromatic ring in peak box 1 and peak box 3 shows the *t*-butyl group. Peak box 2 integrates as only one acetoxy peak where there should be two as there is in the NMR spectrum for HRI's standard diacetoxy(phenyl)- λ^3 -iodane. This peak could come from a single acetoxy group being attached to iodine or it could simply be residual acetic acid trapped in the viscous oil product.

In order to understand the discrepancy between the two molecules a sample of the brown oil compound was sent to Baron Consulting Group to test for iodine content. The idea behind this test was that if there was no iodine in the sample there was no logic in moving forward with the current reaction path. The sample was combusted and then titrated potentiometrically with silver nitrate which formed a white precipitate. Silver iodine is bright yellow and there did not appear to be any yellow color in the remaining solid. The test suggested that there was no

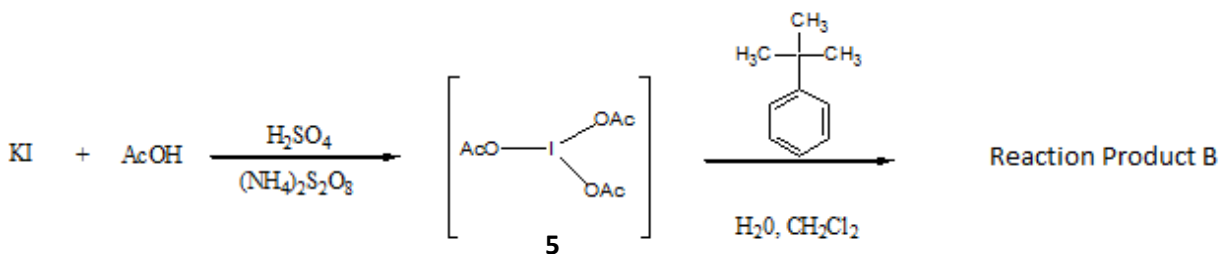
iodine in the sample. The attempted reaction had not performed as anticipated which gave no further reason to pursue this pathway.

Figure 7. Original reaction product A (brown oil) vs diacetoxy (phenyl)- λ^3 -iodane (HRI)



II. Synthesis of Bis (4-*tert*-butylphenyl) Iodonium hydrogen sulfate via Bis (acetyloxy)- λ^3 -iodanyl acetate

Scheme 2. Proposed synthesis via Bis (acetyloxy)- λ^3 -iodanyl acetate



After observing poor results from the initial synthesis method (Rxn A) it was decided to attempt the secondary reaction route (Rxn B) comprised of the in situ formation of bis (acetyloxy)- λ^3 -iodanyl acetate (**5**). Five lab trials were run in the HRI laboratory with the final three producing a tan crystalline through use of a vacuum chamber to remove all residual solvent caught in the reaction mixture. Reaction time was adjusted for each lab trial which showed very little effect on yield. The results are given in Table 1.1 including percent yield based on potassium iodide as the limiting reagent.

Table 1. 1: Synthesis of unknown reaction Product B

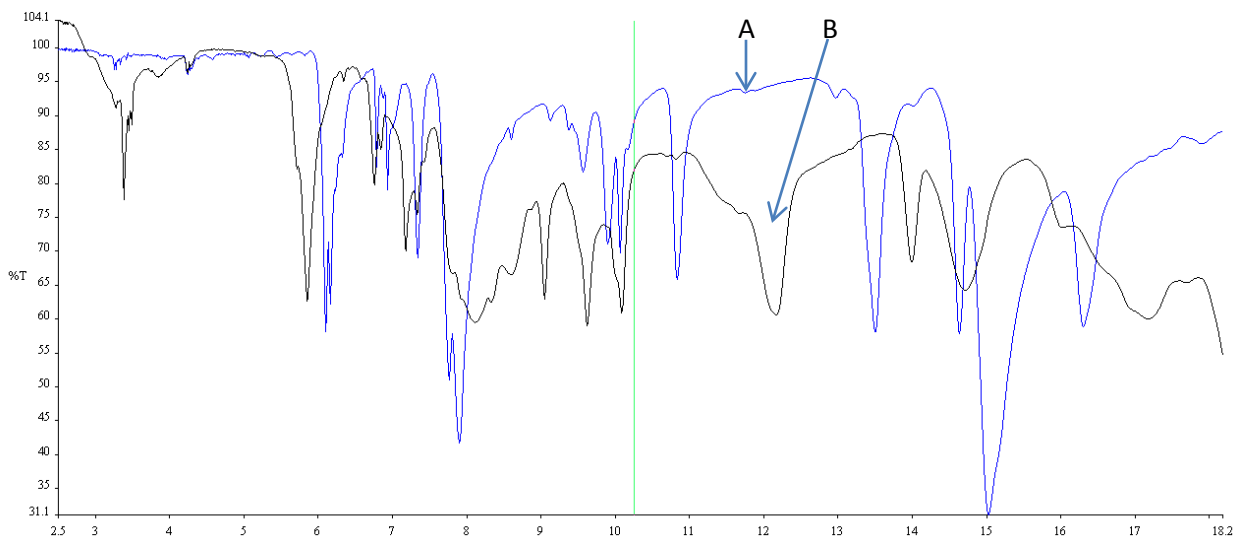
Rxn	Reaction time	Yield (g)	Yield (%)	Description
1A	12	2	n/a	brown oil
2A	20	5	n/a	brown oil
3B	20	6	38	tan crystalline
4B	24	5.5	34	tan crystalline
5B	26	6	38	tan crystalline

III. FTIR Analysis: Reaction Product B

The isolated tan crystalline product for the revised reaction procedure was analyzed using FTIR.

HRI supplied diacetoxy(phenyl)- λ^3 -iodane was used as a benchmark compound for comparison.

Figure 8. Overlay of diacetoxy(phenyl)- λ^3 -iodane(A) and Reaction Product B(B)



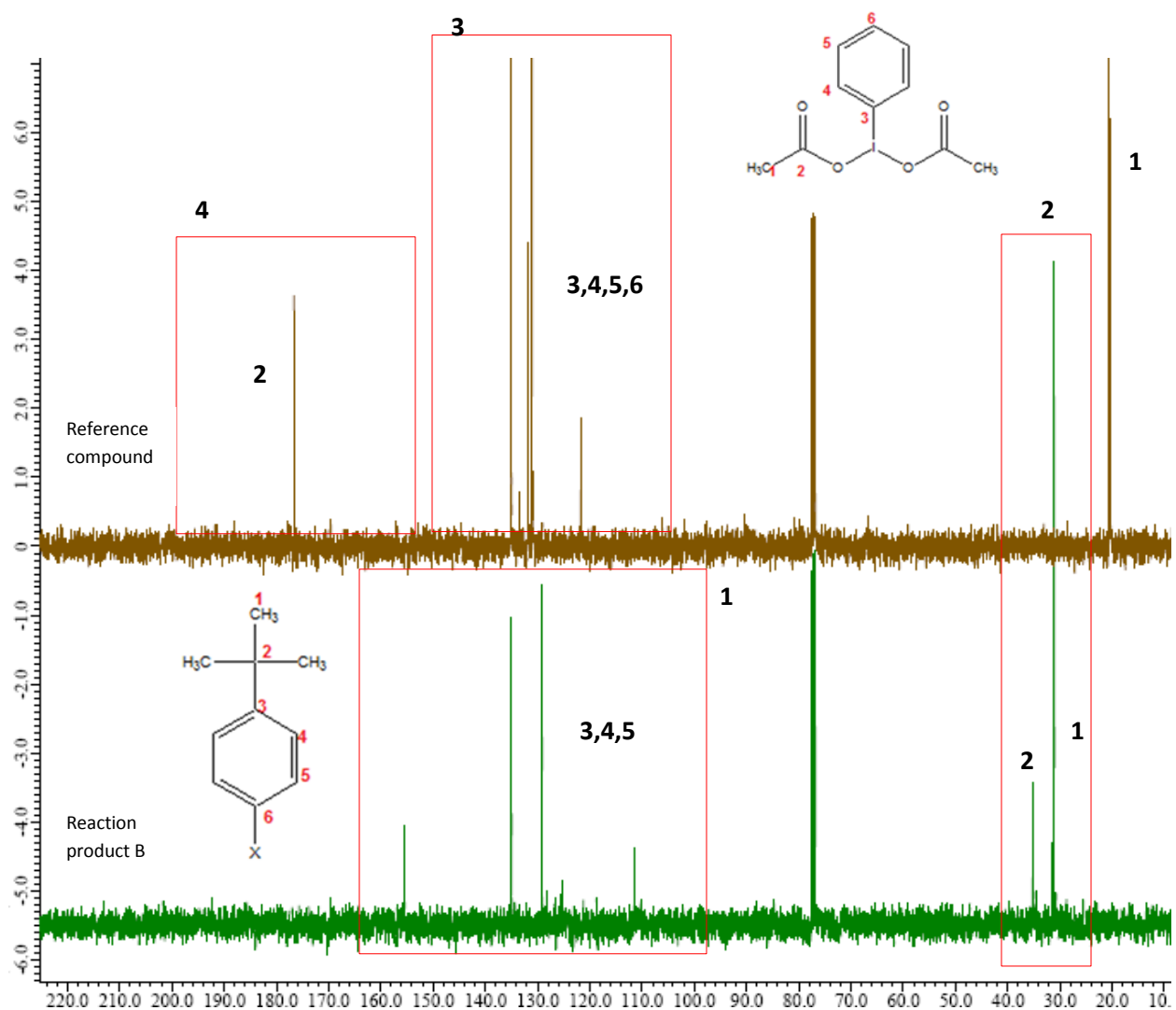
Spectrum B represents reaction product and displays a strong broad para-substituted peak present at 12 microns. Spectrum A represents the HRI supplied diacetoxy(phenyl)- λ^3 -iodane and has no peak in the region for para-substituted. The compare function on the FTIR software is a useful tool to more directly identify differences between the two products. You can clearly see the gap in the diacetoxy (phenyl)- λ^3 -iodane spectrum between 11-13 microns versus the strong peak seen there for the reaction product. These spectra verified that a para-substituted compound was being formed through this reaction route.

IV. NMR Analysis: Reaction B Product

A sample of the reaction product was dissolved in chloroform-d and analyzed using a 400 MHz carbon-13 NMR Spectrometer. The two doublet peaks in box 1 display the carbons on the benzene ring. A total of four peaks indicate that the aromatic ring has two substituents meaning that this molecule is para-substituted. Peak box 2 depicts the carbons on the *t*-butyl group. This was confirmed by comparison with the standard NMR spectrum for *t*-butyl benzene via Sigma Aldrich. What the reaction product spectra was missing was the presence of an acetoxy peak.

The presence of an acetate peak can be seen at the very beginning of peak box 4 around the 175 ppm region for the reference compound, HRI's diacetoxy(phenyl)- λ^3 -iodane. Peak box 3 clearly shows peaks that do not resemble the para-substituted arrangement seen in the reaction product. The comparisons of these spectra lead to the speculation that the target molecule had not been synthesized but instead an unknown para-substituted arene had formed.

Figure 9. Reaction product B vs diacetoxy (phenyl)- λ^3 -iodane



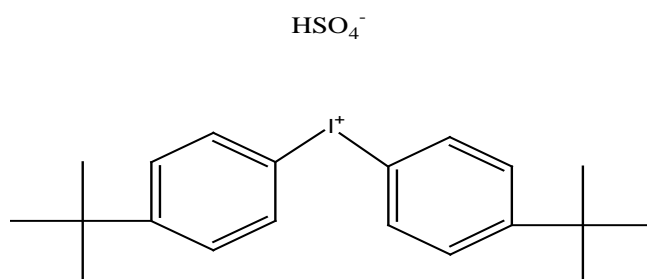
V. Iodine Testing

Again, to settle the uncertainty in the structure of the product, a sample of reaction product B was sent to Galbraith Laboratories for iodine testing. A sample of the reaction product was combusted in a Parr Oxygen Bomb, put into solution and then titrated potentiometrically with silver nitrate to form a yellow precipitate. After weighing this precipitate it was concluded that the sample was composed of 28.8% iodine. This confirmed that the reaction product contained iodine. In an attempt to identify a possible structure, the sample was also run through an elemental analysis test including carbon, hydrogen and sulfur analysis.

Table 1.2: Elemental Analysis – reaction product B

Analysis	Percent Composition Theoretical bis(4- <i>tert</i> -butylphenyl) iodonium hydrogen sulfate	Percent Composition Theoretical <i>t</i> -butyl iodobenzene hydrogen sulfate	Percent Composition Experimental	Sample Amount Used (mg)
Carbon	49.08	33.72	52.13	2.15
Hydrogen	5.35	3.68	4.44	2.15
Iodine	26.93	35.53	28.81	11.66
Sulfur	6.55	9.0	3.5	9.6

The experimental results best matched with the bis(4-*tert*-butylphenyl) iodonium hydrogen sulfate composition as can be seen above. This led to the revised hypothesis of this reaction forming the bis-(4-*tert*-butylphenyl)iodonium hydrogen sulfate (**6**) compound due to an excess of *t*-butyl benzene in the reaction mixture.



VI. FTIR Analysis: Bis (4-*tert*-butylphenyl) Iodonium Hexafluoroantimonate

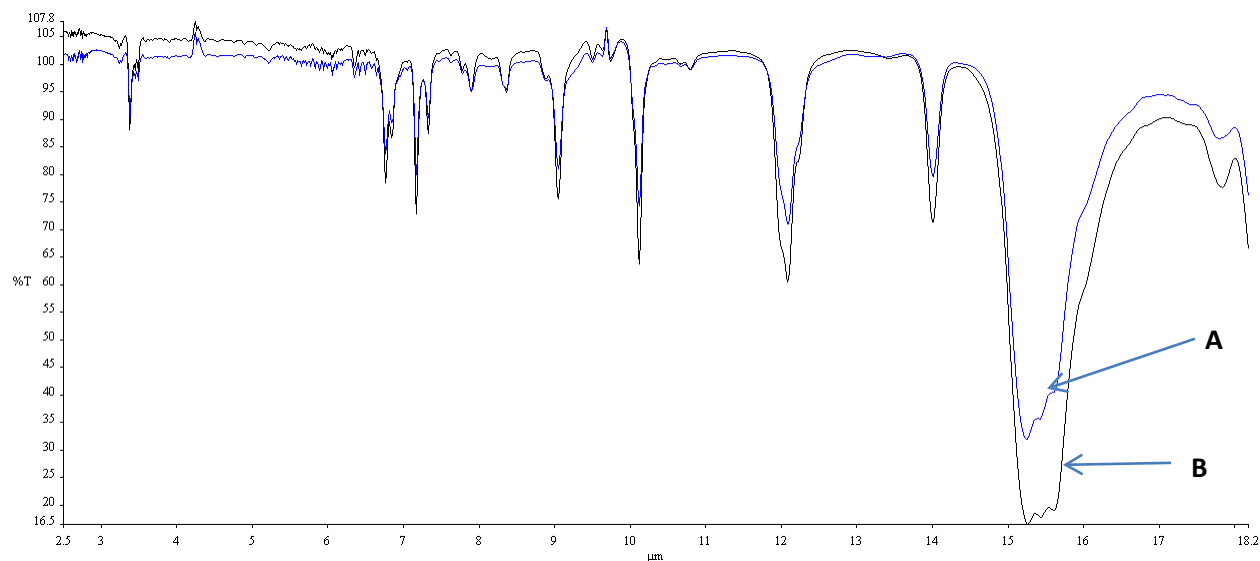
More verification was needed to figure out what the structure was and if it could be reacted to form a known arylodonium compound. Three lab trials were run to make the bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate compound.

Table 1.3: Synthesis of Diaryliodonium Salt: BtPhI SbF6

Entry	Reaction time	Yield (g)	Yield (%)	Description
1	40	3	19	Off white powder
2	40	5	32	Off white powder
3	40	5	32	Off white powder

As mentioned before, the hexafluoroantimonate exchange can be determined via FTIR by the presence of a strong 15 micron peak. Looking at the spectra for the BtPhI SbF6 the 15 micron peak is clearly present. Secondary conformation can be observed when comparing with HRI's bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate.

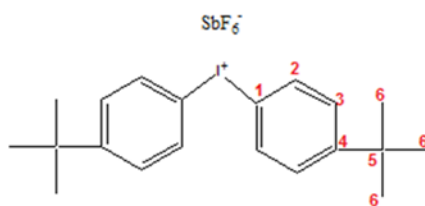
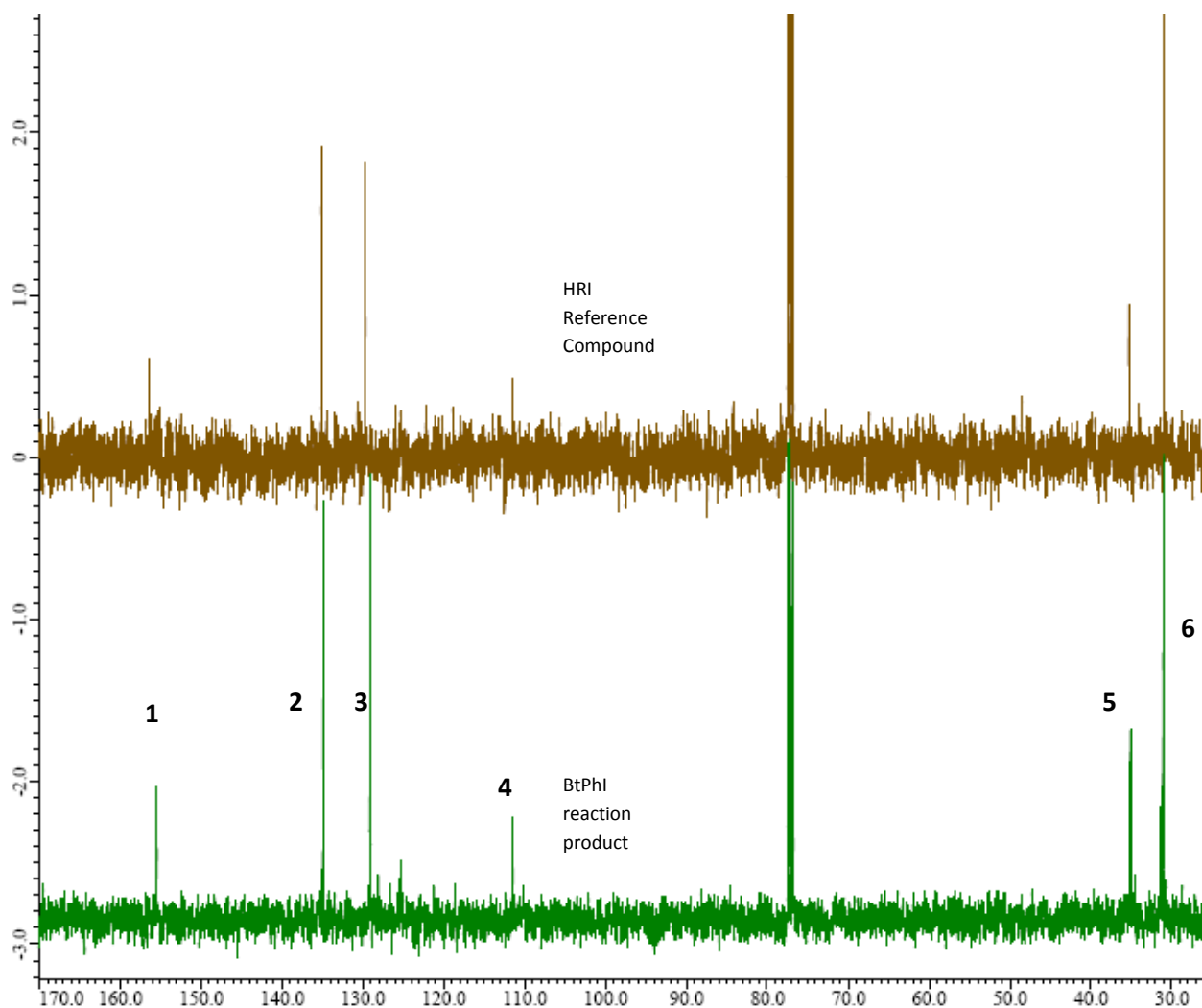
Figure 10. BtPhI SbF6 (A) vs HRI's BtPhI hexafluoroantimonate (B)



VII. NMR Analysis: Bis (4-*tert*-butylphenyl) Iodonium Hexafluoroantimonate

The unknown BtPhI hexafluoroantimonate reaction product was analyzed in chloroform-*d* via carbon-13 NMR.

Figure 11. BtPhI hexafluoroantimonate (HRI) vs BtPhI reaction product



This was then followed by running an NMR on an HRI sample of bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate. This compound was chosen due to the hypothesis that the reaction made a di-*tert* butyl compound based on the excess *t*-butyl benzene used in the initial reaction. These two compounds showed similar spectra's but because the NMR can only see one side of a symmetrical molecule additional testing was needed to confirm the final structure. As a result a sample of the BtPhI SbF6 reaction compound was sent to Galbraith labs for elemental analysis.

VIII. Elemental analysis: Bis (4-*tert*-butylphenyl) Iodonium Hexafluoroantimonate

In order to confirm the structure was in fact a diaryliodonium salt a sample of the proposed BtPhI SbF6 was sent to Galbraith Laboratories for elemental analysis. Similar to the iodine testing that was performed earlier the bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate crystalline compound was combusted in a Parr Oxygen Bomb. The sample was then titrated for iodine and antimony. After weighing the precipitate it was concluded that the sample was composed of 18.8% iodine and 17.1% antimony. The test provided more evidence that bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate had been synthesized.

Table 1.4: Elemental analysis - Bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate

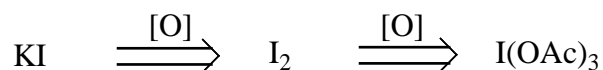
Analysis	Percent Composition Theoretical	Percent Composition Experimental	Sample Amount Used (mg)
Carbon	38.19	40.91	2.15
Fluorine	18.12	17.04	5.64
Hydrogen	4.17	4.44	2.15
Iodine	20.17	18.81	11.66
Antimony	19.36	17.5	10.28

Chapter 3 - Conclusions

This study has led to several realizations regarding the synthesis of iodoarenes as well as diaryliodonium salts. The first experimental procedure described was successful in the formation of a para substituted benzene. The first reaction product was isolated as brown oil which is common for this class of molecule but a crystalline form was desired for use in further reactions. Unfortunately the pursuit of this reaction path was cut short after receiving confirmation by elemental analysis that no iodine had been bonded to the phenyl ring.

The alternate synthesis route involving the formation of bis (acetyloxy)- λ^3 -iodanyl acetate followed by electrophilic substitution of *t*-butyl benzene resulted in a crystalline product. FTIR comparison with monosubstituted diacetoxy(phenyl)- λ^3 -iodane confirmed that the molecule of interest was in fact a para substituted arene shown by a broad peak present at 12 microns. Carbon-13 NMR analysis took a closer look at the sample to confirm the presence of acetate in HRI's diacetoxyiodobenzene but not in the reaction product sample. The unknown sample was tested for iodine content by titration which concluded that *t*-butyl benzene had incorporated iodine. It is hypothesized that changing the order of addition lead to an oxidation reaction that broke the potassium iodide bond forming iodine (I_2). With aqueous iodine present in the reaction mixture, it could then continue to react as described in scheme 3 below. The formation of bis (acetyloxy)- λ^3 -iodanyl acetate followed by addition of *t*-butyl benzene resulted in the incorporation of iodine but the exact structure was still unknown.

Scheme 3. Hypothesized Iodine Oxidation Route



The NMR provided a better idea of what the structure of this compound was by confirming there were no acetate groups present. By comparing the experimental composition with the theoretical composition of *t*-butyl iodobenzene hydrogen sulfate and bis (4-*tert*-butylphenyl) iodonium hydrogen sulfate it was hypothesized that the bis-(4-*tert*-butylphenyl) iodonium hydrogen sulfate was made. This could have been the result of an excess of *t*-butyl benzene in the reaction mixture driving the reaction to produce the diaryl compound. With the elemental analysis complete the next step was to make a known diaryliodonium salt using the bis-(4-*tert*-butylphenyl) iodonium hydrogen sulfate reaction product.

To confirm that the intermediate product could form a diaryliodonium salt, HRI's bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate reaction was reproduced. The reaction produced an off white crystalline solid which was analyzed by carbon-13 NMR and compared to HRI's standard, bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate. This benchmark compound was chosen based on the hypothesis that the large excess of *t*-butyl benzene could have driven the reaction to form a diaryliodonium compound.

The carbon-13 NMR showed the same spectra for both samples but as these are both symmetrical compounds it might not show the whole picture. Elemental analysis was used to confirm that the BtPhI SbF₆ compound had the same elemental composition as the bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate (figure 20). This had identified the product's structure and confirmed the ability for this reaction procedure to produce a diaryliodonium salt.

In hindsight this result might be expected as the synthesis of similar compounds via analogous reactions are well known in the chemical literature.¹⁷ The initial synthesis technique to form the diacetoxy (*t*-butylphenyl)-λ³-iodane was novel but unfortunately unsuccessful. After the reaction had

been completed, analysis revealed we had not made what we set out to make but instead had formed the bis (4-*tert*-butylphenyl) iodonium hydrogen sulfate which was converted to the SbF₆ salt.

Considering this reaction procedure was designed for future large scale production at HRI the manufacturing feasibility and commercial impact must be discussed. The reaction procedure involving the formation of bis (acetyloxy)- λ^3 -iodanyl acetate to produce a diaryliodonium compound was chemically feasible due to the mild reaction steps involved. It is also important to note that the use of potassium iodide in place of elemental iodine was successful in forming a diaryliodonium salt.

The reaction's limiting factor is low percent yield. Yields lower than 40% (table 1.1) are difficult to justify in any industrial chemical environment considering that every time a reaction is run over half of the raw materials involved are wasted. That being said, more work is needed to improve the efficiency of this reaction before it can be considered for large scale production. The financial potential is there with the ability to form a diaryliodonium salt in a one pot synthesis as long as the robustness of the reaction can be improved. With diaryliodonium salts becoming more popular in the photo active chemical market there is always room for improvement on the production efficiency of these compounds.

Chapter 4 - Experimental Procedures

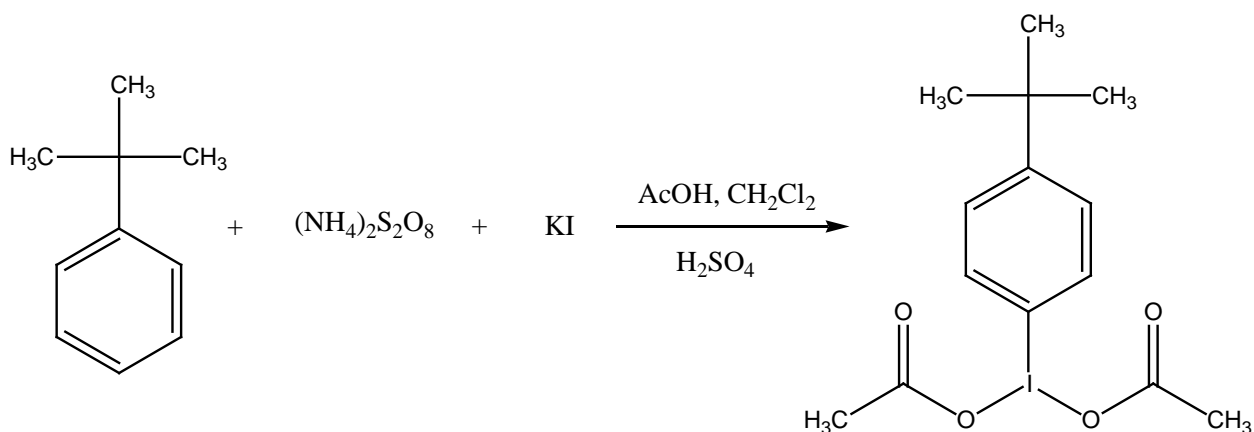
Equipment:

- Paragon 1000 FTIR with Perkin Elmer Precisely software
- Jeol 400 MHz Eclipse NMR Spectrometer.
- Agilent 1100 series LC

I. Attempted Synthesis of diacetoxy(*t*-butylphenyl)- λ^3 -iodane

A simple one-pot synthesis of diacetoxy (*t*-butylphenyl)- λ^3 -iodane would involve the treatment of a mono-substituted aromatic hydrocarbon with a commercially available oxidant and iodine source in an acidic environment. *t*-Butyl benzene provides a phenyl group source which is prepared for iodination with the addition of concentrated sulfuric acid. The iodine is taken from the potassium iodide and an excess of acetic acid provides the acetate source.

Scheme 1. Proposed One-pot synthesis of *t*-butyl (diacetoxyiodo) benzene



For this reaction *t*-butyl benzene, ammonium persulfate, potassium iodide and sulfuric acid were supplied by Aldrich Chemical Co. (Milwaukee, WI) which were all used as received. Technical grade methylene chloride and acetic acid were used as received. Reactions were run under atmospheric

pressure in a 500 mL 3-neck glass reaction flask using a varistat agitation motor and Teflon paddle. A solution of 106 grams (1.8 moles) of acetic acid and 24 grams (0.18 moles) of *t*-butyl benzene was added to the reaction vessel and allowed to stir for 15 minutes. Following the *t*-butyl benzene addition, 45 grams (0.20 moles) of ammonium persulfate was added incrementally. The reaction was then cooled to 15°C using an ice water bath. Once at temperature, 32 grams (0.32 moles) of concentrated sulfuric acid was added via addition funnel at a rate of 18 drops per minute. With the acid added, 16 grams (0.10 moles) of potassium iodide were added in half gram increments using a weigh boat every 15 minutes. No exotherm was observed but the reaction mixture did change to an orange color right after the first addition. After about 2 hours the reaction mixture reverted back to a white/light yellow solution. The reaction was then allowed to stir at ambient temperature for 20 hours.

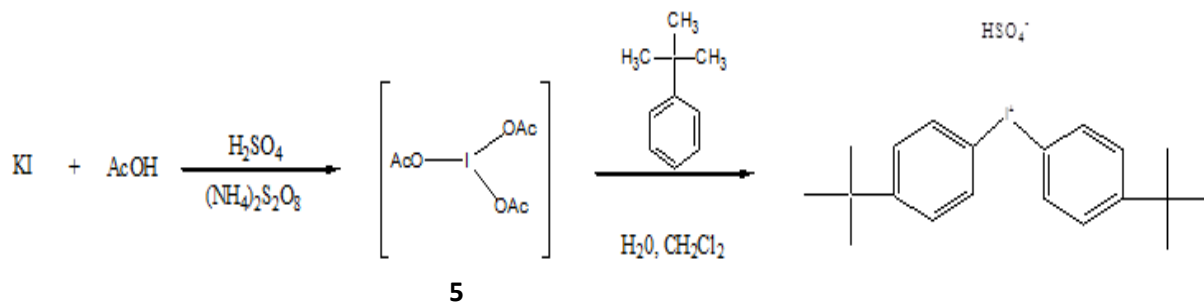
After the reaction hold was completed the product solution was washed with water. Methylene chloride (54g) was then added to extract out the organic material. This mixture was poured into a separatory funnel and the bottom organic layer was removed from the aqueous solution. With the organic layer isolated, the methylene chloride was evaporated off leaving behind viscous light brown oil. Attempts were made to crystallize the product using cold hexane but no crystals were formed.

II. Synthesis of Bis (4-*tert*-butylphenyl)iodonium hydrogen sulfate via Bis (acetyloxy)- λ^3 -iodanyl acetate

After observing poor results from the initial synthesis method it was decided to attempt the secondary reaction route. This alternate route included the formation of bis (acetyloxy)- λ^3 -iodanyl acetate resulting in the diacetoxy (*t*-butylphenyl)- λ^3 -iodane. A solution of 106 grams (1.8 moles) of acetic acid and 16 grams (0.10 moles) of potassium iodide were added to the reaction vessel and allowed to stir for 15 minutes. Following the hold, 32 grams (0.32 moles) of concentrated sulfuric acid was added via addition funnel at a rate of 18 drops per minute. With the addition complete, add 45 grams (0.20 moles) of ammonium persulfate incrementally. Finally, the reaction was then cooled using an ice water bath and 24 grams (0.18 moles) of *t*-butyl benzene was added. The reaction was then allowed to stir at ambient temperature for 20 hours.

After the reaction hold was completed the product solution was washed with water. Methylene chloride (54g) was then added to extract out the organic material. This mixture was poured into a separatory funnel and the bottom organic layer was removed from the aqueous solution. With the organic layer isolated, methylene chloride was evaporated off leaving behind 6 grams of tan crystalline bis (4-*tert*-butylphenyl)iodonium hydrogen sulfate.

Scheme 2. Proposed synthesis of Bis (4-*tert*-butylphenyl) iodonium hydrogen sulfate via Bis (acetyloxy)- λ^3 -iodanyl acetate



III. Synthesis of Bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate

This reaction is a HRI trade secret and is protected under the HRI employee NDA agreement. Specific details regarding the reaction cannot be discussed. The general procedure involves the bis (4-*tert*-butylphenyl)iodonium hydrogen sulfate being added to solvent where it is allowed to stir for an hour. With the product in solvent the hexafluoroantimonate anion is introduced and reacted for up to 8 hours. Finally the product is removed from the solvent via filtration.

Appendix:

Figure 12 Overlay of diacetoxy(phenyl)- λ^3 -iodane(A) and Reaction Product B(B)

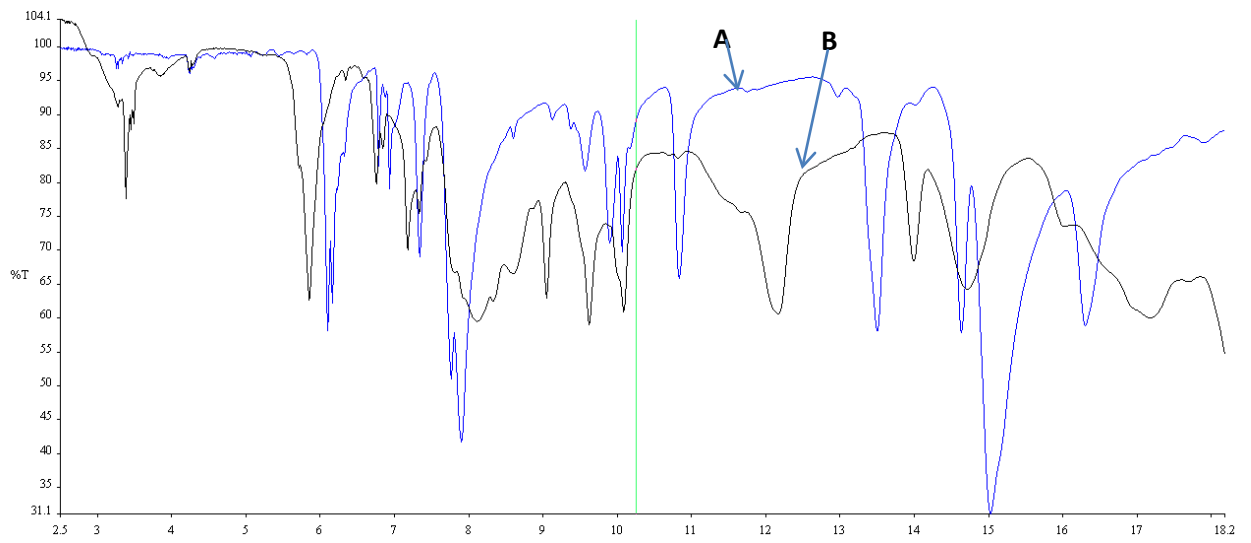


Figure 13. FTIR of HRI supplied diacetoxy(phenyl)- λ^3 -iodane

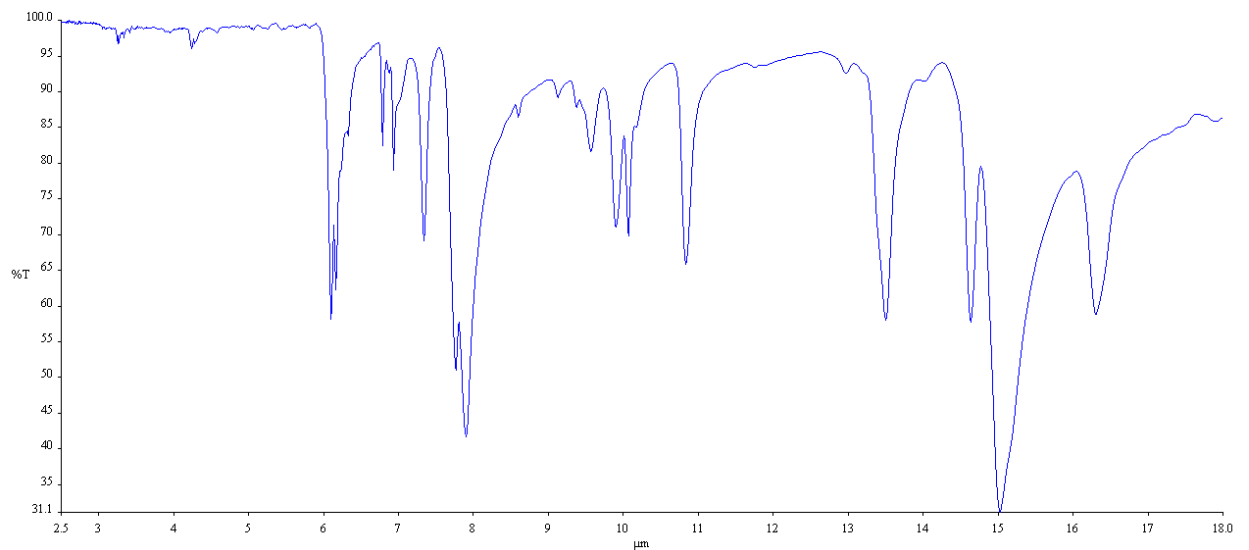


Figure 14. FTIR scan after 12 hour reaction product B reaction

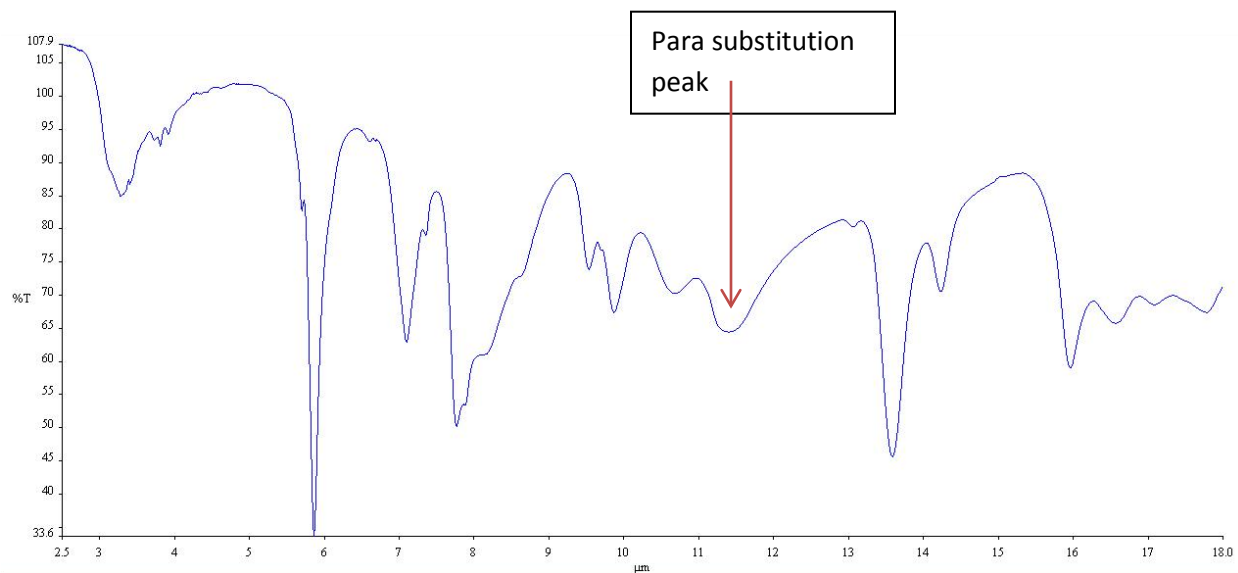


Figure 15. FTIR scan after 20 hour reaction product B reaction

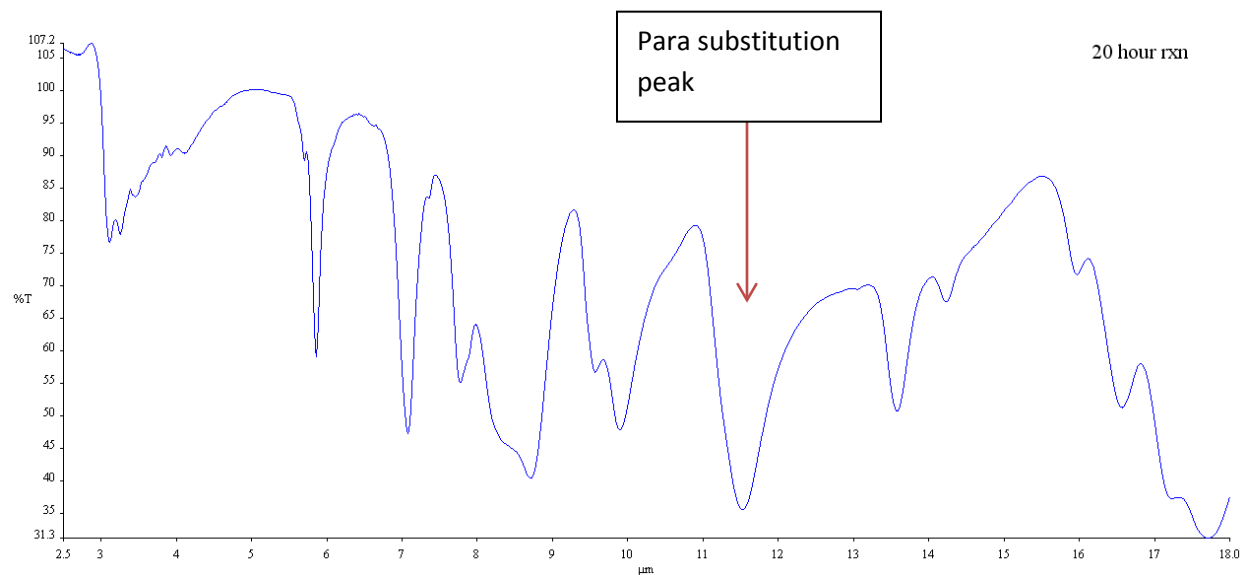


Figure 16. Reaction product B

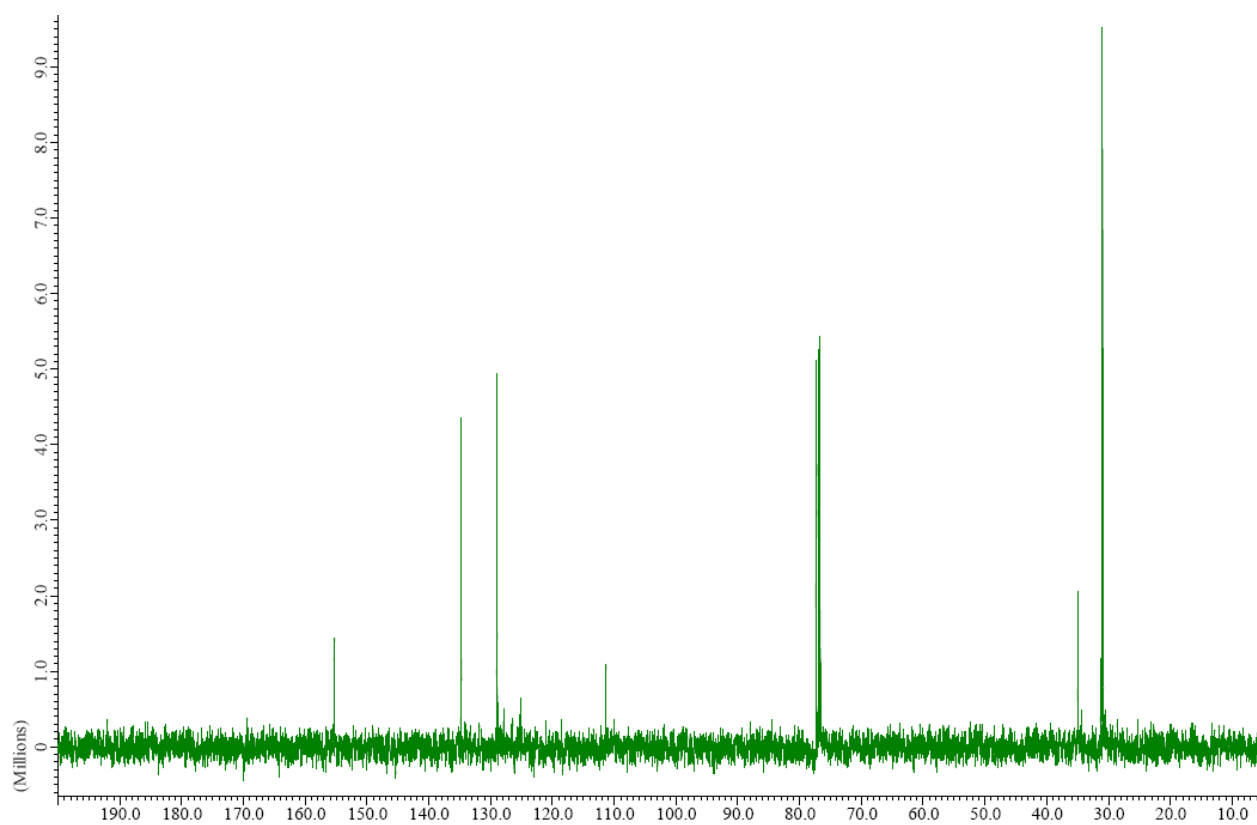


Figure 17. Diacetoxy (phenyl)- λ^3 -iodane (HRI)

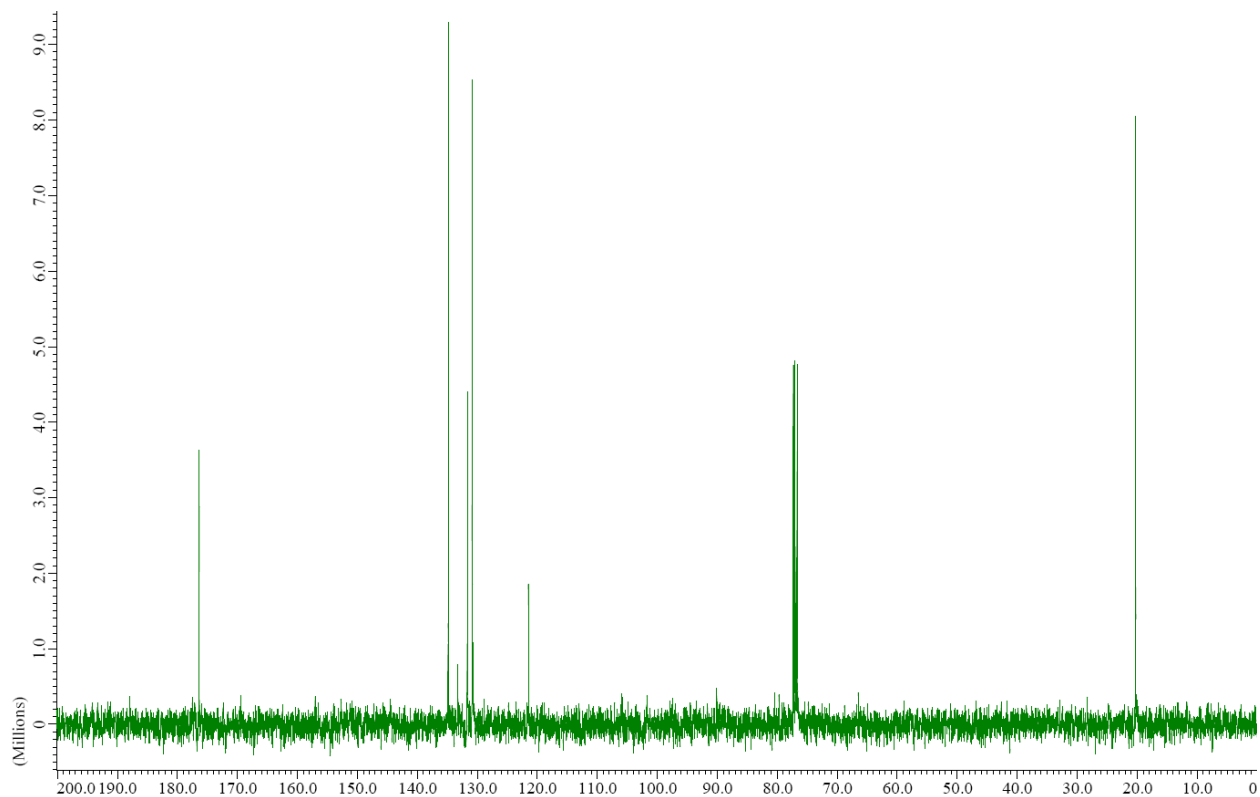


Figure 18. *t*-Butyl benzene NMR Spectrum

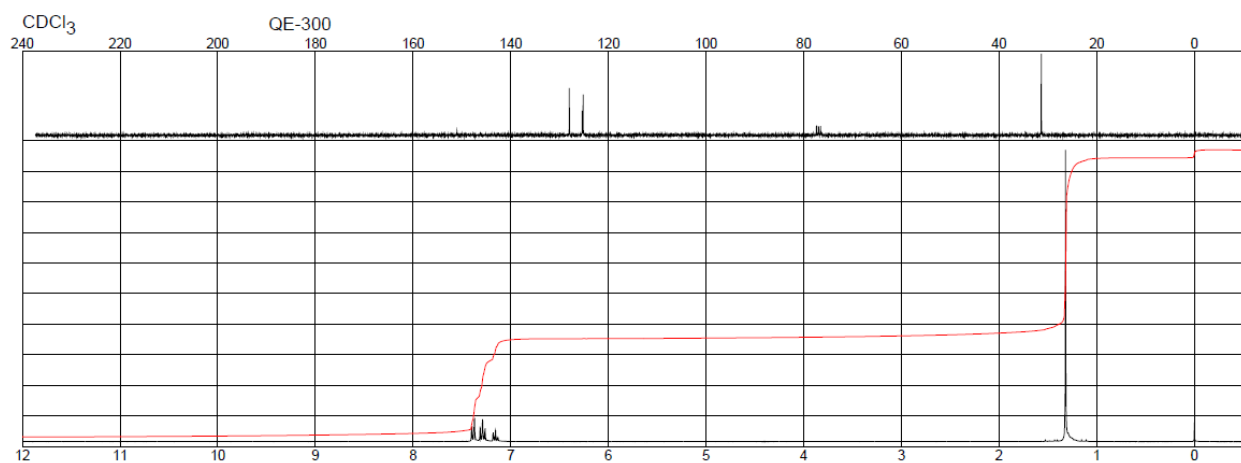


Figure 19. Bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate via bis (acetyloxy)- λ^3 -iodanyl acetate route

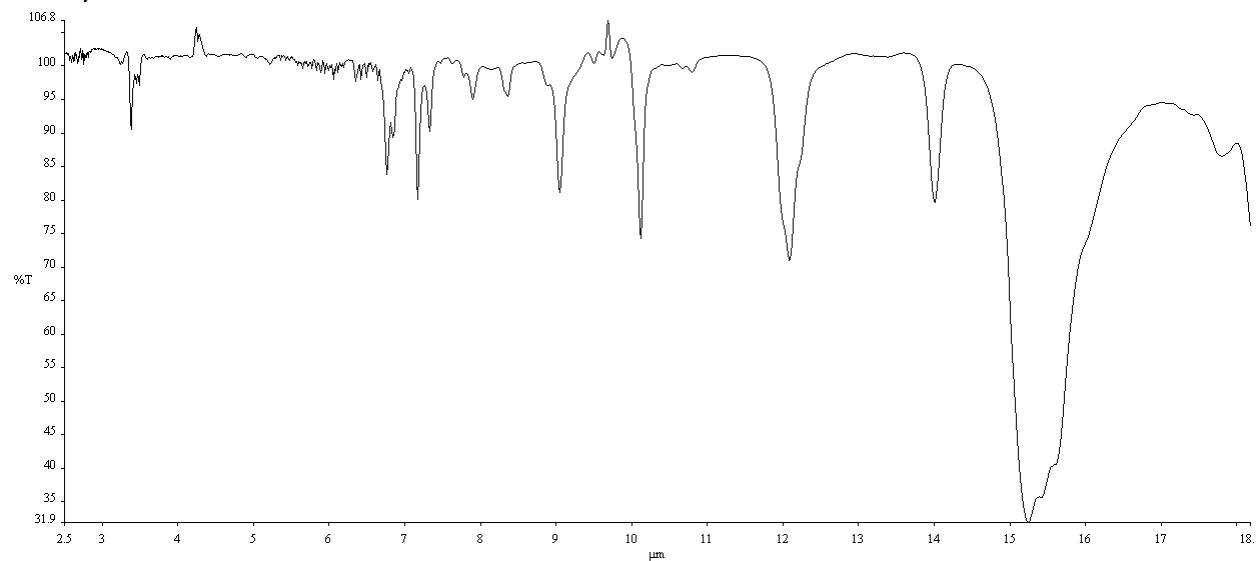


Figure 20. Bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate

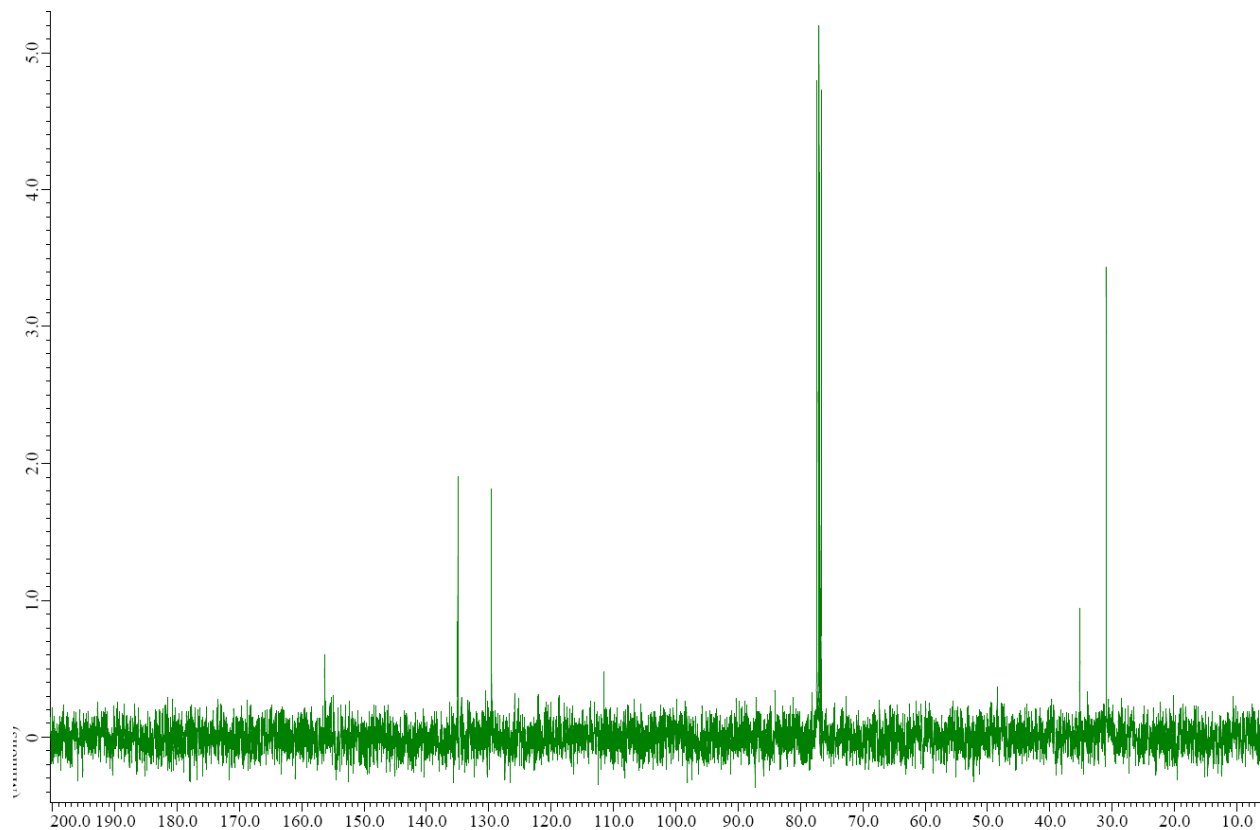


Figure 21: Table 1.2: Elemental Analysis – Reaction product B

Analysis	Percent Composition Theoretical Bis (4- <i>tert</i> -butylphenyl)iodonium hydrogen sulfate	Percent Composition Theoretical <i>t</i> -butyl iodobenzene hydrogen sulfate	Percent Composition Experimental	Sample Amount Used (mg)
Carbon	49.08	33.72	52.13	2.15
Hydrogen	5.35	3.68	4.44	2.15
Iodine	26.93	35.53	28.81	11.66
Sulfur	6.55	9.0	3.5	9.6

Figure 22: LC Spectrum of 90% pure Bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate

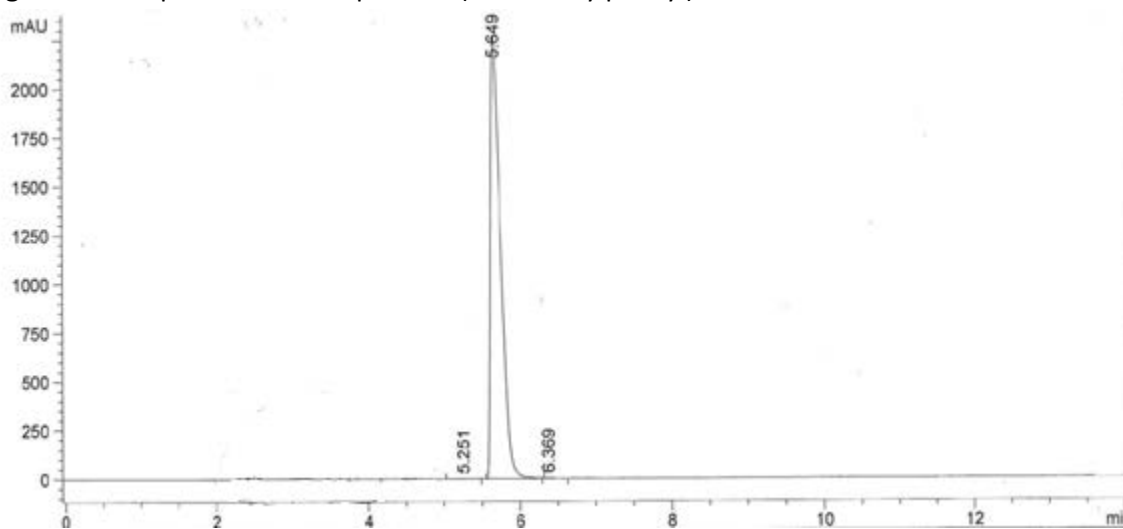
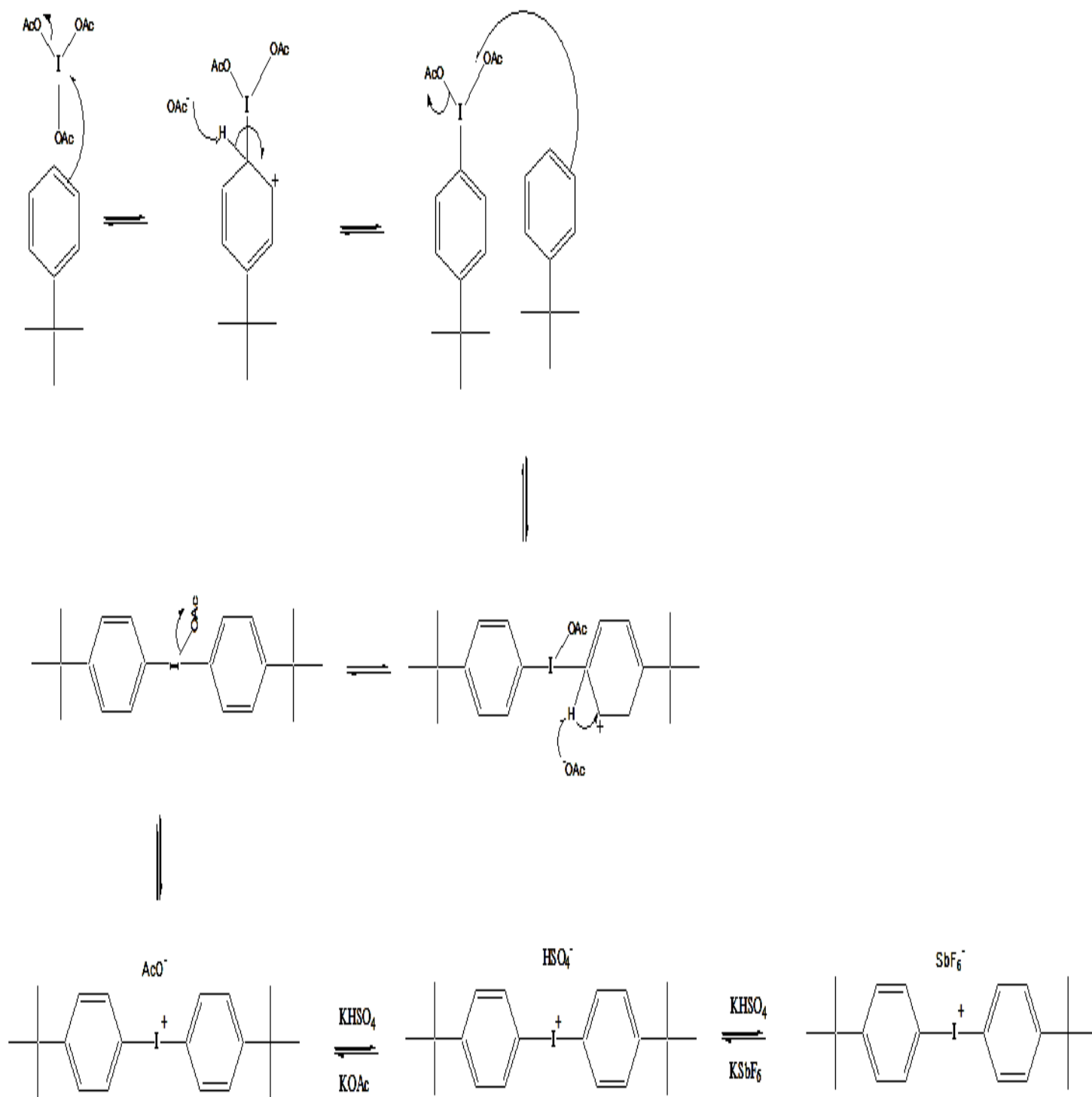


Figure 23: Elemental analysis - Bis (4-*tert*-butylphenyl) iodonium hexafluoroantimonate

Analysis	Percent Composition Theoretical	Percent Composition Experimental	Sample Amount Used (mg)
Carbon	38.19	40.91	2.15
Fluorine	18.12	17.04	5.64
Hydrogen	4.17	4.44	2.15
Iodine	20.17	18.81	11.66
Antimony	19.36	17.5	10.28

Scheme 4. Hypothesized mechanism for the formation of Bis (4-*tert*-butylphenyl) iodonium Hexafluoroantimonate via Bis (acetyloxy)- λ^3 -iodanyl acetate



References

1. Wirth, T; Krische, M.J. Hypervalent Iodine Chemistry: Modern Developments in Organic Synthesis. *J. Am. Chem. Soc.* **2003**, *125*, 11136–11136.
2. Merritt, E. A.; Olofsson, B.; Diaryliodonium salts: A journey from obscurity to fame. *Angew. Chem. Int. Ed.* **2009**, *48*, 9052.
3. Zhao, B. ; Cheng, K.; Hu, L.; Aryl substituted indolizine derivative useful in treatment of cancer and its preparation *Faming Zhuanli Shenqing* **2013**, CN 102977098 A 20130320
4. Jalalian, N.; Development and Applications of Hypervalent Iodine Compounds. Thesis. Stockholm University, Sweden 2012.
5. K.Y. Akiba, Ed., Chemistry of Hypervalent Compounds. Wiley-VCH, New York, NY, USA, 1999.
6. Pauling, L.; The Nature of the Chemical Bond; Cornell University, Ithaca, NY, **1948**.
7. Dess, D. B.; Martin, J. C.; Readily accessible 12-I-5 oxidant for the conversion of primary and secondary alcohols to aldehydes and ketones. *J. Org. Chem.* **1983**, *48*, 4155.
8. Zhdankin, Viktor V.; Stang, Peter J.; Recent Developments in the Chemistry of Polyvalent Iodine Compounds. *Chem. Rev.* **2002**, *102*, 2523-2584.
9. Hossain, D.; Kitamura, T.; Direct, easy, and scalable preparation of (diacetoxyiodo) arenes from arenes using potassium peroxodisulfate as the oxidant *Tetrahedron Letters*. **2006**, *47*, 7889–7891.
10. Edmunds, J. J.; Novel Fluorination Reactions via Hypervalent Iodine Reagents. *J. Am. Chem. Soc.* **1988**, *53*, 517-538.

11. Crivello, J. V.; Polymerizable Compositions Containing Radiation Sensitive Halonium Salts. Canadian Patent 1,274,646 September 25, **1990**.
12. Kokkinidis, G.; Papadopoulou, M.; Varvoglis, A.; Electrochemical reduction of [bis(acyloxy)iodo]arenes. *Electrochimica Acta* **1989**, *34*, 133-9.
13. Kitamura, T.; Inoue, D.; Wakimoto, I.; Nakamura, T.; Katsunob, R.; Fujiwarab, Y.; Reaction of diacetoxy(phenyl)- λ^3 -iodane with excess of trifluoromethanesulfonic acid. A convenient route to para-phenylene type hypervalent iodine oligomers. *Tetrahedron Letters* **2004**, *60*, 8855–8860.
14. Tomoya M.; Yui N.; Masao M.; Masahiro M.; Enantioselective Synthesis of Anti Homoallylic Alcohols from Terminal Alkynes and Aldehydes Based on Concomitant Use of a Cationic Iridium Complex and a Chiral Phosphoric Acid. *J. Am. Chem. Soc.* **2013**, *135*, 11497-11500.
15. Yusubov S.; Maskaev V.; Zhdankin V.; Iodonium salts in organic synthesis. Department of Chemistry and Biochemistry, University of Minnesota Duluth, USA **2011**.
16. Sorrell, Thomas N.; Organic Chemistry, Second Edition. University Science Books, **2006**
17. Ohashi, Masaki; Kinsho, Takeshi; Ohsawa, Youichi; Hatakeyama, Jun; Tachibana, Seiichiro; Polymerizable anion-containing sulfonium salt and polymer, resist composition, and patterning process. United States Patent 20100055608 March 4, **2010**.