

PhI(OTf)₂ Does Not Exist (Yet)

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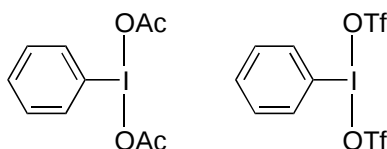
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ABSTRACT

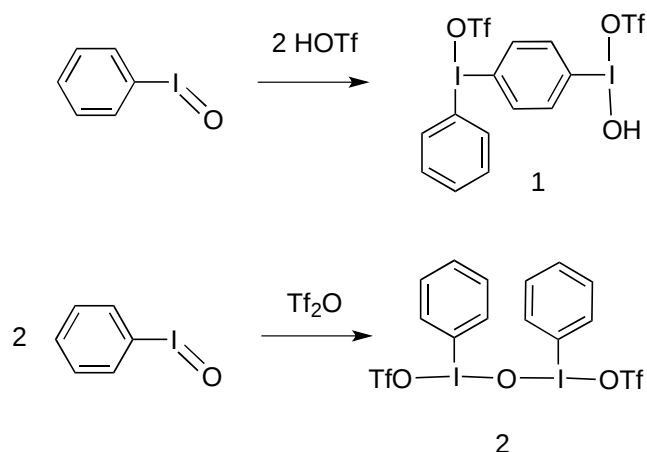
PhI(OTf)₂ has been used for the past 30 years as a strong I(III) oxidant for organic and inorganic transformations. It has been reported to be generated *in situ* from the reactions of either PhI(OAc)₂ or PhI=O with two equivalents of TMS-OTf. In this report it is shown that neither of these reactions generate a solution with spectroscopic data consistent with PhI(OTf)₂ and thus this compound should not be invoked as the species acting as the oxidant for transformations that have been associated with its use.

INTRODUCTION

Diacetoxyiodobenzene ($\text{PhI}(\text{OAc})_2$) and related species are a versatile I(III) oxidants with applications in organic and inorganic chemistry.^{1, 2} Replacement of the acetate ligands with more electron poor fragments results in derivatives that are stronger oxidants.³ One such derivative with an increased oxidative capacity is $\text{PhI}(\text{OTf})_2$ which has had reported use as an *in situ* generated species in solution by several groups, including our own. In organic chemistry $\text{PhI}(\text{OTf})_2$ has purported use in formation of hydrazones,⁴ oxyaminations,⁵ dizaeniums,⁶ synthesis of functionalized cyclopropane rings,⁷ and alpha arylations.⁸ We have used it as a starting complex to form Weiss' reagent, $[\text{PhI}(\text{Pyr})_2]^{2+}$ via displacement of the triflates.^{9, 10}

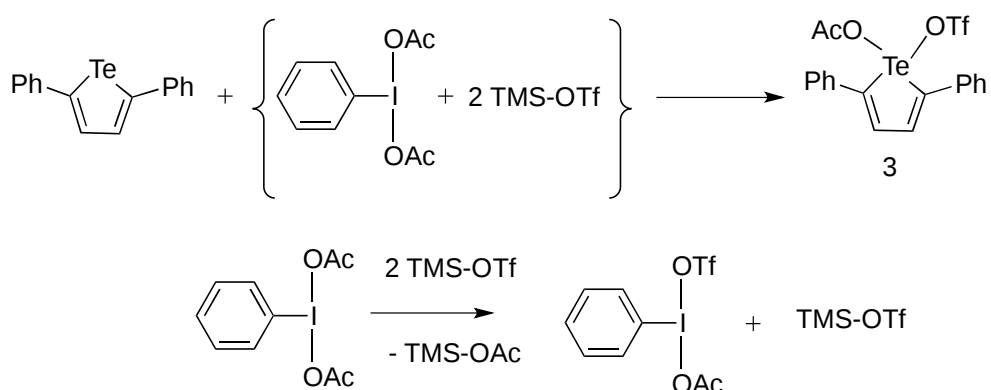


Syntheses of $\text{PhI}(\text{OTf})_2$ have been reported by the reaction of two equivalents of TMS-OTf with $\text{PhI}(\text{OAc})_2$ or two TMS-OTf with $\text{PhI}=\text{O}$,^{4, 5, 8, 10} with the first report coming from Zhdankin using TMS-OTf and $\text{PhI}=\text{O}$.¹¹ It was postulated that two equivalents of triflic acid may react with $\text{PhI}=\text{O}$ to generate $\text{PhI}(\text{OTf})_2$ but was found in actuality to generate 1 which could be used to generate bisiodonium salts.¹² Similarly it was suggested that triflic anhydride may react with $\text{PhI}=\text{O}$ in a 1:1 fashion to generate $\text{PhI}(\text{OTf})_2$; but experimental results were inconsistent with $\text{PhI}(\text{OTf})_2$ and more consistent with that of structure 1.^{13, 14} Reactions of $\text{PhI}=\text{O}$ with half an equivalent of triflic anhydride are known to give Zefirov's reagent (2).¹⁵



Scheme 1. Reactions of $\text{PhI}=\text{O}$ with triflic acid and triflic anhydride

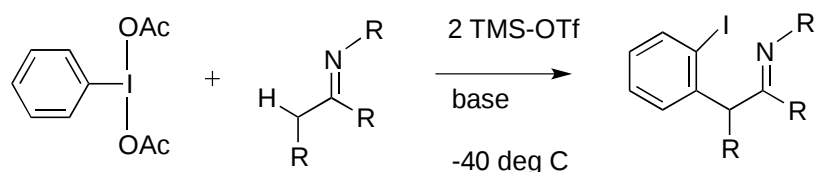
While investigating the chemistry of " $\text{PhI}(\text{OTf})_2$ " with tellurophenes we isolated the mixed acetate/triflate Te(IV) species 3.¹⁶ This led us to closely examine the proton NMR spectrum of the mixture of the reaction of $\text{PhI}(\text{OAc})_2$ with two equivalents TMS-OTf which clearly showed the species generated under these conditions is in fact $\text{PhI}(\text{OTf})(\text{OAc})$ (Scheme 2). The identity of the $\text{PhI}(\text{OTf})(\text{OAc})$ (generated from the reaction of equimolar amounts of $\text{PhI}(\text{OAc})_2$ with TMS-OTf) was shortly thereafter confirmed in a remarkable piece of crystallography on this reactive species by Shafir et al.¹⁷



Scheme 2. Reaction of $\text{PhI}(\text{OAc})_2$ with two TMS-OTf stopping at $\text{PhI}(\text{OTf})(\text{OAc})$.

A recent paper published in *The Journal of The American Chemical Society* reporting the arylation of 2-oxazolines employs $\text{PhI}(\text{OAc})_2 / 2\text{TMS-OTf}$ as the oxidant and uses the structure

PhI(OTf)₂ as a starting point for theoretical calculations on the reaction mechanism.⁸ However, as detailed above, the reaction of PhI(OAc)₂ with two equivalents of TMS-OTf does not result in generation of PhI(OTf)₂ either at room temperature or at -40 °C as specified in the study. The outcomes of their syntheses are not at all in question here, but rather the starting point of PhI(OTf)₂ in their theoretical studies cannot be correct.



Scheme 3. Reaction of PhI(OAc)₂ with 2-oxazolines in the presence of two TMS-OTf, which was proposed to proceed via PhI(OTf)₂ as an intermediate

Given the continued use of PhI(OAc)₂/2 TMS-OTf as a purported method of generating PhI(OTf)₂ we decided it was timely for a detailed study on the possible synthesis and existence of PhI(OTf)₂ from both a synthetic and theoretical perspective using this method and the original method from PhI=O and two TMS-OTf.

RESULTS AND DISCUSSION

From PhI(OAc)₂ and 2 TMS-OTf

Experimental reports on this reaction are detailed in our previous paper,¹⁶ which show that this reaction stops at PhI(OTf)(OAc). The structure of PhI(OTf)(OAc) was later corroborated in a separate study by Shafir and co-workers.¹⁷

Theoretical calculations on the free energy profile for the reaction were performed at the wPBE/def2-TZVP level of theory. We found that many common theoretical methods do a poor job of reproducing the geometry for bound triflate in comparison to experimental reports. The wPBE/def2TZVP method gives results consistently close to experimentally reported values across the species of interest in this study.

The calculated ΔG for the reaction $\text{PhI}(\text{OAc})_2 + \text{TMS-OTf} \rightleftharpoons \text{PhI}(\text{OTf})(\text{OAc}) + \text{TMS-OAc}$ is -80 kJ/mol, consistent with experimental observation that this reaction proceeds to completion.

From this point however, the reaction of $\text{PhI}(\text{OTf})(\text{OAc}) + \text{TMS-OTf} \rightleftharpoons \text{PhI}(\text{OTf})_2 + \text{TMS-OAc}$ has a calculated ΔG of $+23$ kJ/mol. Considering the overall reaction $\text{PhI}(\text{OAc})_2 + 2 \text{TMS-OTf} \rightleftharpoons \text{PhI}(\text{OTf})_2 + 2 \text{TMS-OAc}$ gives a value of -57 kJ/mol. This theoretical data is consistent with our experimental observation that the reaction stops at $\text{PhI}(\text{OTf})(\text{OAc})$ and the 23 kJ/mol free energy well this product is in compared to $\text{PhI}(\text{OTf})_2$ solidly supports that $\text{PhI}(\text{OTf})_2$ should not be invoked as a species in this reaction system.

From PhI=O

The reaction of 2TMS-OTf with PhI=O in CH_2Cl_2 , the original report of $\text{PhI}(\text{OTf})_2$, was described to rapidly generate a yellow solution from which low melting crystals or oily substances of $\text{PhI}(\text{OTf})_2$ could be isolated.¹¹ The byproduct was $\text{Me}_3\text{Si-O-SiMe}_3$ and the proton NMR chemical shifts at 60 MHz in CD_2Cl_2 were reported to be multiplets at 8.2 (2H) and 7.5 ppm (3H).

The calculated ΔG for the reaction is -79 kJ/mol, indicating the reaction is thermodynamically feasible. Considering the experimental report and calculated negative ΔG we decided to reinvestigate the reported reaction. It should however be noted the PhI=O

is a polymeric, insoluble solid¹⁸ and the energy penalty for breaking up and solubilizing the polymer is not considered in the -79 kJ/mol.

PhI=O was suspended in CD₂Cl₂ and two equivalents of TMS-OTf were added resulting in the immediate generation of a colourless solution. A ¹H NMR spectrum was taken which in the upfield region of the spectrum Me₃Si-O-SiMe₃ and unreacted TMS-OTf were observed in an approximate 3:1 ratio.⁹ In the aromatic region broad peaks in the locations Zhdankin reported at 8.2 and 7.5 ppm were present. Iodobenzene, however, was the most abundant species, with at least one other compound present. After 16 hours, the compound giving broad signals at 8.2 and 7.5 ppm disappeared and was replaced with signals consistent with a disubstituted and a monosubstituted aryl group. A mass spectrum of a sample of the reaction mixture added to CH₃CN gave a signal with *m/z* at 406.9 in positive ion mode, consistent with the cation [C₆H₅-I-C₆H₄-I]⁺, which is also consistent with signals in the ¹H NMR spectrum. A ¹H NMR taken in DMSO-d₆ to compare with literature data confirms this cation as the remaining product.¹⁹

Regarding the intermediate, which is consistent with the PhI(OTf)₂ spectrum proposed by Zhdankin, in both CDCl₃ and CD₂Cl₂, the -ortho aryl protons in PhI(OAc)₂ resonate at 8.10 ppm.²⁰ For PhI(OAc)(OTf) the -ortho protons resonate at a chemical shift of 8.25 ppm.¹⁶ It would be expected that another substitution of acetate for more electron poor triflate would lead to a further downfield chemical shift for these protons, thus a signal at 8.2 ppm is not consistent with PhI(OTf)₂. The observation that not all the TMS-OTf is consumed in the reaction is also inconsistent with formation of PhI(OTf)₂. In summary, PhI=O reacted with two equivalents of TMS-OTf does not generate a solution of PhI(OTf)₂ based on ¹H NMR data.

Triflic anhydride has been suggested to possibly react in equimolar quantities with PhI=O to generate PhI(OTf)₂,¹³ but it has also been found to actually give compound 1,¹⁴ and also gives onward reactions consistent with that class of species. Reaction of half an equivalent of triflic anhydride with PhI=O has been reported to give Zefirov's reagent.¹³ The calculated ΔG for the reaction with one equivalent of triflic anhydride giving PhI(OTf)₂ is -168 kJ/mol. The calculated ΔG for the reaction with a half equivalent of triflic anhydride giving Zefirov's reagent is -232 kJ/mol, indicating stopping at this point should be the thermodynamic sink for the reaction.

These ΔG values considered, we decided to revisit the reaction of PhI=O and triflic anhydride in CD₂Cl₂ in an equimolar ratio, to compare the results with our observations for PhI=O and two TMS-OTf. The ¹H NMR spectrum of the reaction mixture showed no peaks consistent with the report of PhI(OTf)₂ with no resonances around 8.2 ppm. At least two unique phenyl groups were present in the mixture with the most downfield peak at 8.5 ppm, but being a minor product. The ¹⁹F NMR spectrum contained unreacted triflic anhydride at -71 ppm and a resonance at -78 ppm consistent with anionic triflate, and a minor resonance at -76 ppm, which is consistent with a bound triflate and Zefirov's as previously reported.

Reaction of triflic acid with PhI=O to give PhI(OTf)₂ is also calculated to be favourable at -85 kJ/mol, giving water as a byproduct. Reaction of PhI=O with 2 equivalents of TfOH in CD₂Cl₂ gave a ¹H NMR spectrum similar to that of the reaction from triflic anhydride, with a mixture of peaks in the aryl region in the *in situ* NMR spectrum consistent with the general structure of 1 as previously described¹² and no evidence for the presence of PhI(OTf)₂.

These observations, with triflic acid and triflic anhydride giving different products than the reaction of $\text{PhI}=\text{O}$ with 2 TMS-OTf, indicate that the intermediates generated in the TMS-OTf reaction must differ.

CONCLUSION

In this study we have shown that the methods reported to generate $\text{PhI}(\text{OTf})_2$ do not give solutions of this species. The most common modern purported method, $\text{PhI}(\text{OAc})_2 + 2 \text{TMS-OTf}$ stops at one metathesis conclusively giving $\text{PhI}(\text{OTf})(\text{OAc})$, and $\text{PhI}(\text{OTf})_2$ should not be invoked from this mixture. For the reaction of two TMS-OTf with $\text{PhI}=\text{O}$, while calculated to be thermodynamically feasible, we do not believe $\text{PhI}(\text{OTf})_2$ is generated and then decomposes as only half of the TMS-OTf is consumed when the reaction ceases at room temperature and the NMR data of the reaction mixture is not consistent with $\text{PhI}(\text{OTf})_2$. In summary, while reactions using the above methods previously reported in the literature all result in compounds containing oxidizing I(III) sources which have been used effectively for organic transformations, the molecule $\text{PhI}(\text{OTf})_2$ itself does not (yet) exist.

EXPERIMENTAL SECTION

Acknowledgements

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