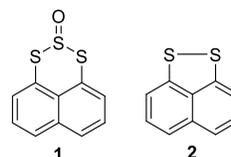


**PRF Grant:** 57667-ND3  
**Project Title:** Sulfur and Selenium Monoxide Transfer Reagents  
**P.I.:** Nicholas E. Leadbeater, University of Connecticut, USA  
**Co-PI:** Richard S. Grainger, University of Birmingham, United Kingdom

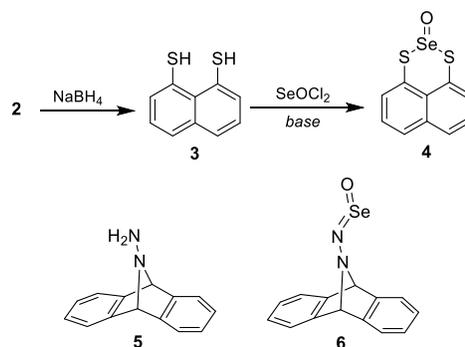
## INTRODUCTION

The overarching goal of our PRF-funded work is the development of new main-group chemistry, specifically the incorporation of sulfur monoxide (SO) and selenium monoxide (SeO) into organic and inorganic molecules. Both these diatomic molecules are unstable and so need to be generated in-situ. The Grainger group in Birmingham has previously prepared and used SO transfer agent **1**. It is generated from disulfide **2**. Selenium monoxide has not been used synthetically and a practical method for its generation is not known. Our objectives for the second year of the project have been to develop novel SO transfer reagents and, using the results from this as a launching point, prepare SeO transfer reagents. The project involves students at both the University of Connecticut and the University of Birmingham. In the first year of the funding period, a graduate student from Connecticut spent a month working with the Birmingham group. In this second year, a graduate student from Birmingham has spent a month working in the Connecticut group.



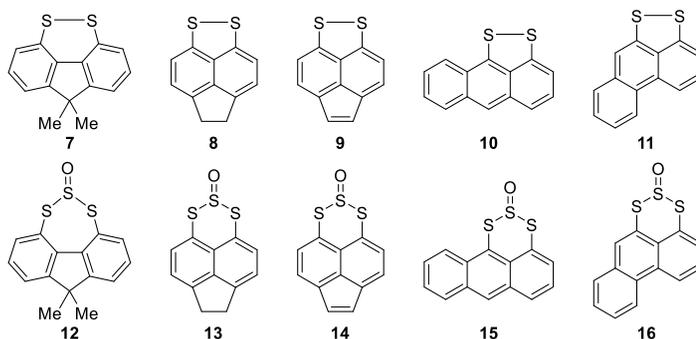
## RESEARCH PROGRESS – YEAR TWO

In Connecticut, we have continued to focus most of our attention on developing a route to selenium monoxide transfer reagents. At the end of year one we had prepared a putative SeO-containing species using **2** as a backbone. We followed an analogous route to that used by the Grainger group to generate **1** from **2**. Treatment of disulfide **2** with sodium borohydride yielded dithiol **3**. Adding selenium oxychloride to a solution of **3** gave what we believe to be SeO-containing compound **4**. Unlike its sulfur analog **2**, we find that **4** is unstable at room temperature. This impacts the yield of the reaction to generate **4**, as well as its definitive characterization and ultimately its potential use as an SeO transfer agent. We have probed the identity of **4** using a combination of infrared, mass, and <sup>1</sup>H-, <sup>13</sup>C- and <sup>77</sup>Se-NMR spectroscopy. Data is in line with what would be expected for our proposed structure. Given the unstable nature of **4**, we have spent much of year two attempting to prepare alternative SeO-containing species. Cummins and co-workers recently reported an SO transfer agent prepared from Carpino's hydrazine, **5**. Performing some calculations, we discerned that extrusion of SeO from **6**, a transfer reagent derived from **5**, would be favorable and so decided to attempt to prepare this novel compound. Hydrazine **5** was prepared using a modified approach to that used by Cummins in order to avoid a problematic reduction step. We attempted to prepare **6** by treatment of **5** with triethylamine and selenium oxychloride. The reaction mixture immediately produced a red precipitate, indicating the formation of elemental selenium. The mixture was analyzed by <sup>1</sup>H-NMR to discover that there was a 100% conversion of the hydrazine backbone to anthracene, indicating that **6**, if formed, decomposed immediately. Any attempts to add diene to the mixture, in hopes of trapping any SeO formed *in-situ* proved unsuccessful. Experimentally, we are continuing to explore the reaction chemistry of **4**. Alongside this, we are attempting to prepare SeO-containing species derived from the alternative disulfide backbones prepared by the Birmingham group in their studies.



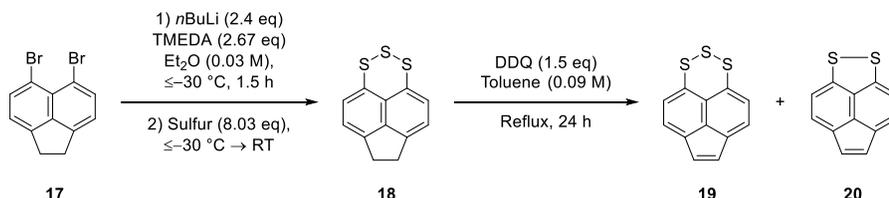
In Birmingham, the syntheses of backbones **7-11** required for the preparation of potential SO transfer reagents **12-16** have been achieved. Studies into the release of SO from fluorene trisulfide-2-oxide **12** have, for the most part, been completed. We can report that while **12** does formally lose SO, the SO is trapped in much poorer yields, both thermally and photochemically, than from **1**.

The Birmingham group have developed a gram-scale synthesis of acenaphthene trisulfide **18** via a lithium-halogen exchange of dibromide **17** followed by quenching with sulfur. The direct formation of trisulfides by quenching organolithium species with sulfur is rare and the sole formation of **18** in this manner is significant. A re-evaluation of the formation of disulfide **7** and



disulfide **2** from the corresponding aryl dilithium species has shown that trisulfides are also present, but only as minor components. These minor trisulfide impurities can be removed upon reduction of the mixture to the dithiol using NaBH<sub>4</sub>, followed by reoxidation to the disulfide. Trisulfide **18** can similarly be reduced to disulfide **8**, although the intermediate dithiol is notably more stable to air oxidation than **3**, making it much easier to work with towards the preparation of trisulfide-2-oxide **13**. Alternatively, trisulfide **18** is potentially only a selective oxidation away from **13**, and this approach is also currently under investigation.

The DDQ oxidation of **18** gives an inseparable mixture of acenaphthylene trisulfide **19** and disulfide **20**, which can again be converted to acenaphthylene disulfide **20** through NaBH<sub>4</sub>-mediated reduction and subsequent oxidation. Acenaphthylene disulfide **20** has rarely been investigated due to its tedious and low-yielding preparation, and so our synthetic route represents a significant improvement and opens up new possibilities for this compound. The successful preparation of **18** and **20** means studies into the synthesis of and properties of **13** and **14** are now feasible.



Anthracene disulfide **10** has also been prepared and investigations into the synthesis of trisulfide-2-oxide **15** have been carried out. However, **15** is light sensitive and rapidly decomposes back to **10**. In contrast phenanthrene trisulfide-2-oxide **16** is much more stable, and shows comparable SO-releasing properties to naphthalene **1**.

## IMPACT OF THE RESEARCH

The funded project has continued to allow the Connecticut and Birmingham groups to participate in a formal international collaboration. Our objective is to use the preliminary results obtained in our PRF-funded project to apply for further jointly funded research through channels such as the US National Science Foundation and the UK Engineering and Physical Sciences Research Council, as well as student exchange programs funded through the Universitas 21 framework, of which both our institutions are a part.

The project has continued to fund a University of Connecticut graduate student (Shelli Miller) to work on the project during the 2018-19 academic year. An undergraduate student from the University of Connecticut (Joshua Paolillo) has been involved in aspects of the work and was directly supervised by Shelli, as has new graduate student Arturo León-Sandoval. The funded work has not only exposed the students to common organic chemistry techniques, but also allowed them to gain experience handling air and moisture sensitive compounds and analyzing complex reaction mixtures to characterize products. In Birmingham, a graduate student (Connor Prior) and a postdoctoral fellow (Dr. Ian Pocock) worked on the project, their chemicals and consumables being funded in part from the PRF grant and their stipend being provided by the UK Leverhulme Trust through a PhD studentship and postdoctoral fellowship, respectively. Connor spent a month at the University of Connecticut working together with Shelli, sharing the approach his group developed for the preparation of backbones **8** and **10** as well as working together on attempts to prepare the SeO transfer reagent derived from these backbones. Connor also took the opportunity to attend the ACS National Meeting in Orlando, FL where he presented a poster on the chemistry of the fluorene SO transfer reagent **12**, and developed some professional networks with academics in the USA.