SUMMER 2022 RESEARCH PROGRAM
CARLETON CHEMISTRY DEPARTMENT

This summer the Carleton Chemistry Department plans to offer another year of its continuing summer research program for Carleton students. Though we cannot guarantee that circumstances will allow an on-campus program to take place, at this point we are hopeful that it will be possible. As the pandemic continues to evolve, we may be forced to limit research opportunities accordingly. However, we are currently moving forward with the application process for on-campus positions. We expect to offer research positions to approximately eight new students. Most of the student researchers will come from the sophomore and junior classes. Professors Chihade, Drew, Gross, Kohen, and Whited will offer projects that are described at the end of this document.

A summer research recruiting seminar will be held on **Friday, January 14th via Zoom (link available on Chemistry Department events page) at 3:30 pm**. General information on summer research in the department will be presented along with more details regarding the application process. A recording of the seminar will be available on the department's Research Opportunities webpage.

Dates of the Program: Monday, June 13th, through Friday, August 19th, for a total of 10 weeks. Each student will arrange starting and ending dates and summer vacation with their professor; these dates can be flexible.

Expected Stipend: $5,000 for 10 weeks (or $500 per week)

Expectations of Students by the Chemistry Department

A research position in our summer research program is a full-time position. You should not plan on taking a second job during the same period.

Each week you will be expected to attend a research meeting with all of our summer researchers. Each student will give an oral presentation on his or her project at this weekly meeting at some point over the summer. You may also have the opportunity to give a presentation on your research at a state or national research meeting. Following the summer of research, you will prepare a comprehensive written report and give a poster on your research at the fall Research Celebration at Carleton.

Deadlines and How to Apply

The application is available here. Follow the directions on the electronic application form to rank order your preferences for the various research projects. Also tell us how strong your preferences are and how flexible you are in accepting a position in the other research groups you list. Before submitting your application, you should talk to individual professors in order to explore your interest in their research project. Keep in mind that some professors will not take a student into their research group unless the student has taken the time to stop by, meet the professor, and discuss the research project. Others may also want additional topics addressed in your application, such as relevant courses and experiences you've had outside of the department. Applications are due at **5:00 pm on Friday, February 18, 2022**.

Offers will go out on **Monday, February 28**. We will ask for your decision on our offer by **Friday, March 11** (the last day of class).

Reasons for Participating in the Summer Research Program

Research requires a demanding combination of intellect, creativity, endurance, and curiosity. Many valuable skills are developed in the research laboratory. Some examples include the ability to work as a member of a team, to operate sophisticated instrumentation, and to use available resources to become a life-long learner. Research is also excellent preparation for graduate school, a career in the medical sciences, or a career in other scientific or quantitative fields.

Choosing to do research at Carleton offers a number of advantages. First of all, you will get to know your professors much better. In addition, you start preparing for your summer research experience during spring term. This additional preparation will improve the quality of the research you can perform during the short ten-week summer. Furthermore, your research project can be continued as appropriate through independent study during the following academic year. Some students at Carleton who have had the most positive research experiences have worked on their research projects over the course of two years. Unlike the experience at a larger institution, colleges like Carleton offer research opportunities exclusively for undergraduate students. At a larger institution, you would probably work most directly with a graduate student or post-doc, which is a good, yet different kind of experience. At Carleton you are guaranteed to work closely with a professor and to have your peers as research colleagues.

Life at Carleton and in Northfield is different during the summer than during the academic year. You will be surprised by the pace, and you will be pleased to know that you will not need your down jacket and warm hat (you may want to buy a fan). Normally, many of the facilities (such as the gym, pools, weekly movies, etc.) at Carleton are open for summer programs. We also hope to have at least two outings, with canoe trips, baseball games, Valley Fair, and tubing having been popular choices in the past.

Professor Joe Chihade – Biochemistry of aminoacyl-tRNA synthetases

Positions for 2-3 new students

The general area of research in my lab are a set of enzymes, the aminoacyl-tRNA synthetases (ARSs), that catalyze the formation of ester linkages between amino acids and the sets of specific transfer RNAs (tRNAs) with corresponding anticodon sequences, so that each of the twenty amino acids is only linked to the tRNAs that pair with the corresponding codons, as defined by the genetic code.

This year, we will be working on three related projects:

• Because they are crucial components of the protein synthesis machinery, ARS enzymes are potential drug targets in the treatment of infectious diseases caused by parasitic organisms. A large number of diseases are caused by helminths, parasitic worms that infect more than one billion people worldwide. We have identified the genes for ARS proteins in these organisms, and are now working to produce and characterize these proteins in the lab, the next step in evaluating which ones are most likely to be good potential drug targets. We will be continuing that work this summer.

• The standard method for measuring the enzymatic action of ARS involves the use of a radioactively labeled amino acid. That method is expensive, slow, and somewhat dangerous. We are working to develop a new type of assay that will allow us to follow the aminoacylation reaction without using radioactivity. Successfully creating such an assay will depend on finding a way to recycle the aa-tRNA ester product by specifically hydrolyzing the ester bond. Several enzymes that might catalyze this reaction exist. Our plan for the summer is to test these enzymes in order to find one that will work best in the context of the aminoacylation assay.

• For the several years, students in my lab have worked on understanding one particular ARS, the enzyme that links alanine to its corresponding tRNA in human mitochondria. Over the past ten years or so, several mutations in this enzyme have been linked to severe diseases, including infantile cardiomyopathy and leukodystrophy, the degeneration of white matter in the brain. The link between particular mutations and the corresponding diseases they cause is still not well understood. By characterizing some of the mutant proteins and comparing their behavior to the wildtype enzyme, we will try to shed some light on this question.

All of the work in my lab involves protein purification, *in vitro* transcription of tRNAs, creation of new RNA and protein mutants using site-directed mutagenesis and other molecular biology techniques, enzymatic assays to measure charging ability, and probing of tRNA structures to determine regions of protein-RNA interactions.

If you are interested in talking more, please set up a meeting with me, either by email or using this link.

Professor Steven Drew: Photoelectrochemical Water Splitting

Positions for 0-2 new students

I may be hiring up to two new students this summer (depending on returning students) to work on an investigation into photoelectrochemical water splitting using evaporatively deposited thin films of mixed metal oxide semiconductors.

I am interested in the development of new, inexpensive techniques for the deposition of thin films of mixed metal oxide semiconductors onto conductive substrates. These types of materials have the potential to serve as photocathodes and photoanodes for the photoelectrochemical splitting of water using sunlight. Successful photocathodes and photoanodes immersed in aqueous electrolyte solution, when exposed to sunlight, will produce excitons capable to splitting water into hydrogen and oxygen, respectively. The collected hydrogen can be used directly as a renewable fuel or serve as a high-energy reactant in other chemical processes. Figure 1 is a representation of an ideal tandem photoelectrochemical cell.

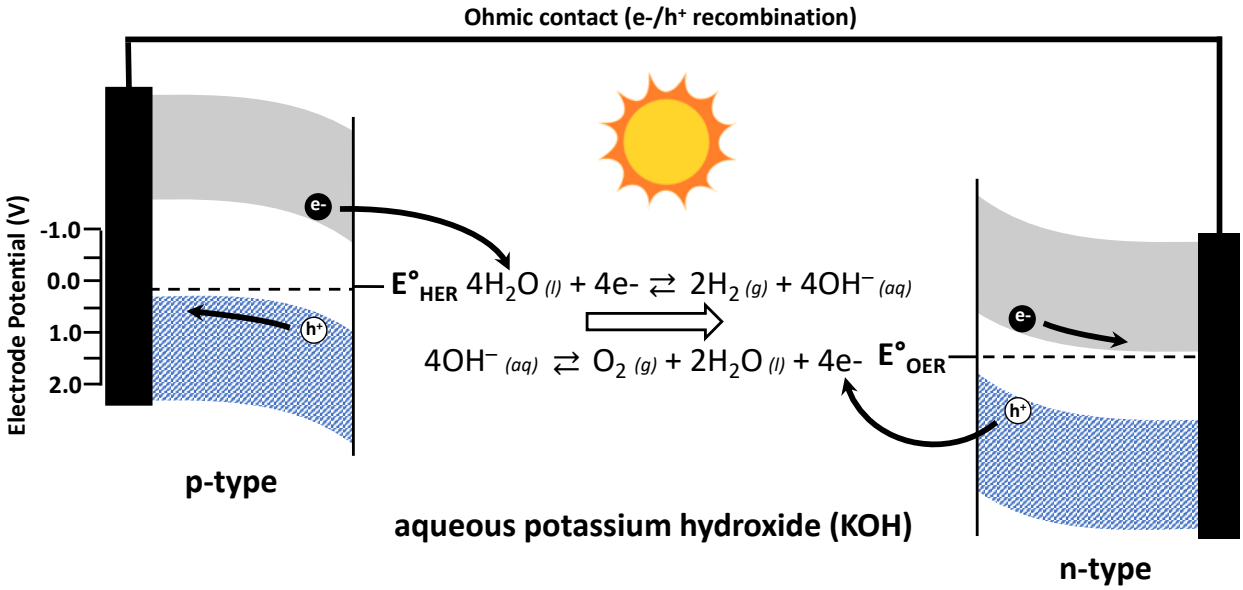


Figure 1. Ideal tandem photoelectrochemical cell. Excitons (e^-/h^+ pairs) are produced by the absorption of sunlight at the semiconductor-electrolyte interface. A p-type mixed metal oxide semiconductor serves as the photocathode driving the hydrogen evolution reaction (HER). A n-type mixed metal oxide semiconductor serves as the photoanode driving the oxygen evolution reaction (OER).

Work in the lab will focus on further developing and characterizing deposition techniques for making thin films of a mixed iron-chromium-aluminum oxide semiconductor. This combination is interesting in that adjustments of the stoichiometry can produce either a p-type (photocathode) or n-type (photoanode) semiconductor. Currently, we are using colloidal metal hydroxides of iron, chromium, and aluminum produced in ammonia solution as the starting materials. Restricted evaporative deposition of the colloidal metal hydroxide solution followed by heating

in a furnace at 550°C leads to metal oxide formation. An interesting dependence of the semiconductor type produced on the concentration of ammonia has been observed (see Figure 2). Scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS) of these films indicates the iron-chromium-aluminum ratio deposited as a function of position on the film. We'll have three major goals for the summer: (1) Explore the possibility of using electrochemical deposition to make thin films of iron-chromium-aluminum oxide on FTO substrates, (2) Further develop our ability to use the SEM-EDS instrument to obtain elemental maps of the thin film semiconductors we make, (3) Determine the effect of film thickness on photocurrent then optimize film thickness to maximize photocurrent.

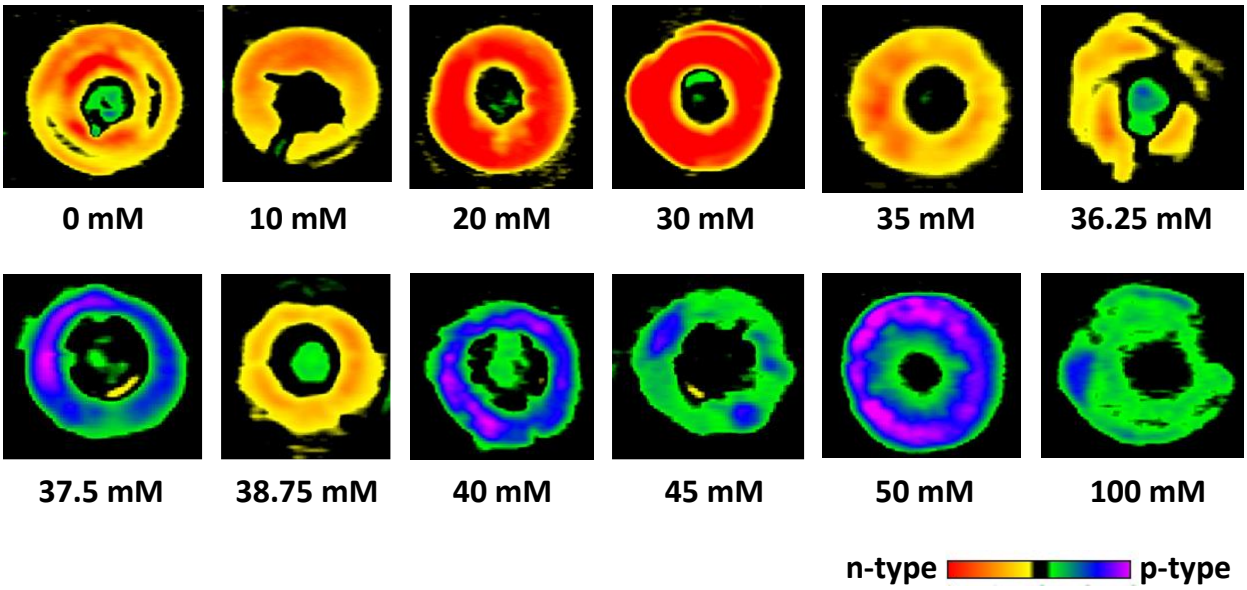


Figure 2. 2D PEC data showing the effect of ammonia concentration on the type of semiconductor obtained using a restricted evaporation technique with colloidal metal hydroxide starting materials. Composition: 3.65 mM $Fe(NO_3)_3$, 5.55 mM $Cr(NO_3)_3$, 0.8 mM $Al(NO_3)_3$

Students working on this research project will have the opportunity to learn how to make thin films of mixed metal oxide semiconductors on FTO substrates using our evaporative deposition technique and possibly electrochemical deposition. In addition, students will also get experience characterizing these thin films using 2D photoelectrochemical (2D PEC) methods, scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS), and X-ray diffraction (XRD) analysis.

I will also be teaching high school students for one week during the summer. For that one week my summer research students will become my teaching assistants and help me work with the high school students to teach them a short course on materials chemistry and perform lab work exploring nanoparticle synthesis.

Professor Deborah Gross: The Chemistry of Atmospheric Aerosol Particles
Positions for ~2 students

The air around us is full of aerosol particles (small droplets or chunks of solids), which impact our lives in many ways. These particles come from natural as well as anthropogenic (human) sources. They nucleate cloud droplets, they decrease visibility by scattering sunlight, and they impact our health when we inhale them. Our research group works with Aerosol Time-of-Flight Mass Spectrometers (ATOFMS) to obtain size and chemical composition information about the aerosol population in real time. With this data, we hope to try to increase our understanding of some of the complex issues in the atmosphere.

Figure 1. One of the Carleton College ATOFMS instruments.

I hope to have ~two students work with me this summer. Students will work collaboratively with the instruments "Wallace" and "Gromit" (see Figure. 1 and will divide up and take on a variety of projects, with the following possibilities available: 1) Continuing to develop data analysis methods to help us identify particle sources from the ATOFMS data signatures; 2) Collecting and analyzing ambient data collected in Northfield and testing methods to convert the number concentration to speciated mass concentration; and 3) Characterizing the particles emitted by "clean" cookstoves in the indoor environment, especially relevant to Ethiopian cooking techniques (see Figure 2). There will also be opportunities to use small, handheld instruments and regional and globally available datasets for community-based projects. Students' interests will drive selection of the projects.

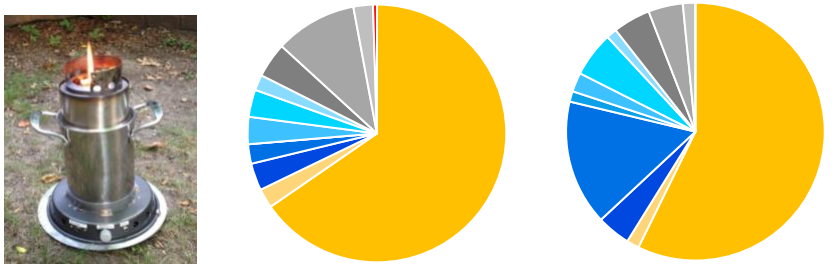


Figure 2. Fraction of particles of various types emitted from a prototype clean cookstove (left) during a water boiling test (middle) and cooking lentils (right). Colors correspond to different particle types, with yellows being elemental carbon, blues being organic carbon, grays being ash, and red being ambient.

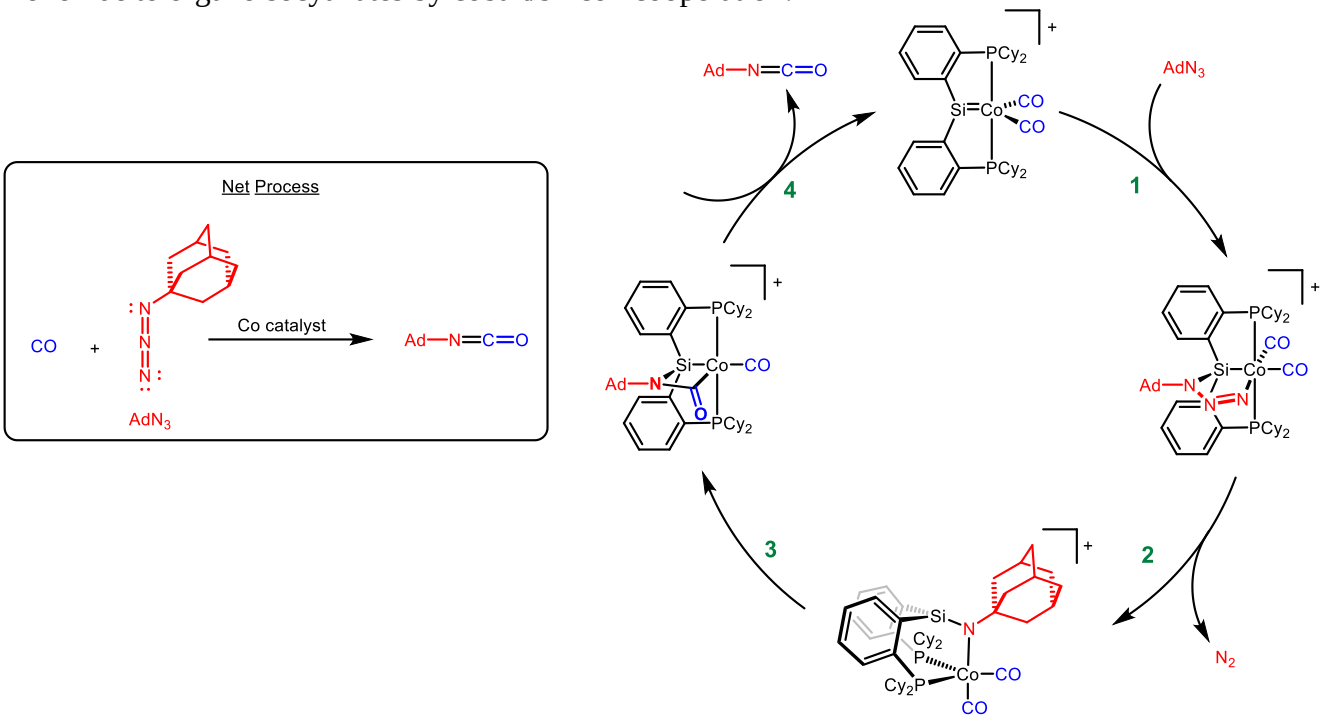
INTERESTED? You should do all of the following things:

- Make a plan to talk with me soon, to discuss the details of the research. It's a requirement for applying that we've talked, either individually or at the open meeting! You can either:
    - Attend an open meeting scheduled on Jan. 27, 4:30 - 5:30 pm on Zoom (link https://carleton.zoom.us/my/deborah.gross. You don't have to be there at the beginning, if you have a lab conflict.
    - Email to make an appointment if you can't attend the open meeting.
- If accepted, plan to enroll in an independent study in Spring, 2022.

Professors Matt Whited and Dani Kohen: Computational Studies of Metal/Silicon Bonds

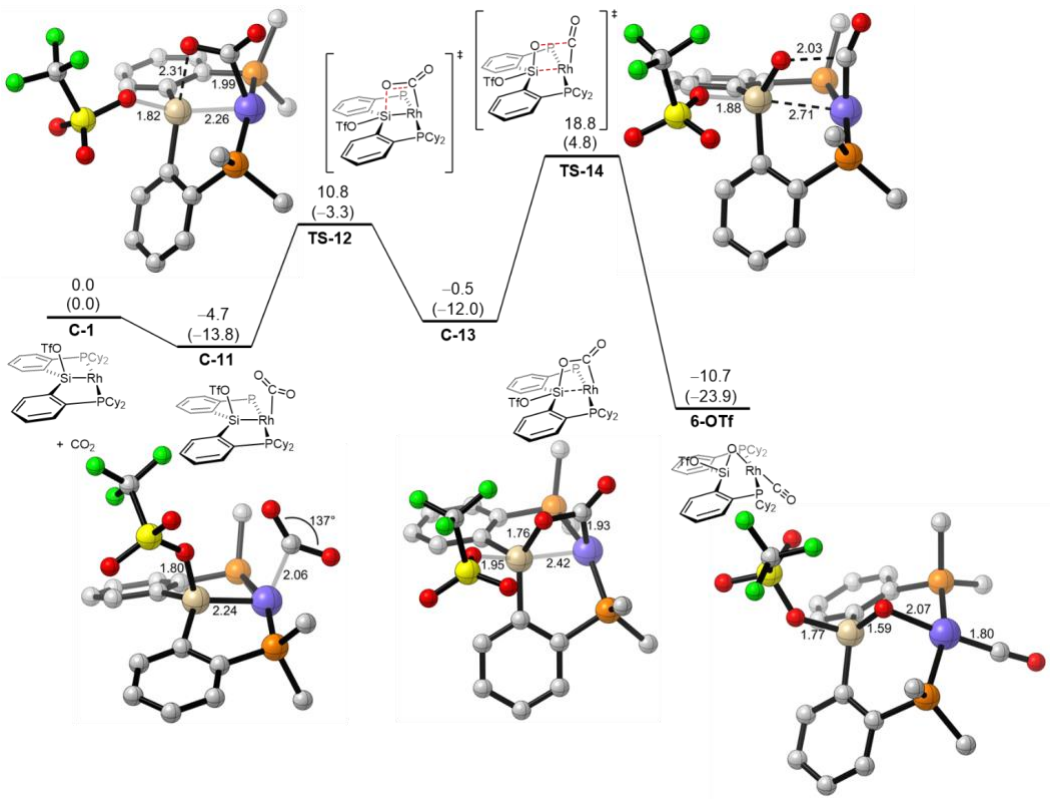
Positions for up to 2 students

In the Whited laboratory, our experimental work aims to develop new chemical transformations of small molecules that are notoriously unreactive, like carbon dioxide, carbon monoxide, and nitrogen gas. Our specific strategy involves promoting catalytic chemical reactions at metal–silicon bonds, allowing us to access new mechanisms by *cooperation* of the two dissimilar elements. One recent exciting finding is the catalytic oxidation of carbon monoxide to organoisocyanates by cobalt/silicon cooperation:



Note that the proposed catalytic mechanism (right) relies on both silicon and cobalt to activate the substrates. Several characteristics of the catalyst complex make this transformation possible, including the (very unusual) Si=Co double bond.

This project uses computational methods to examine unusual organometallic molecules and reactions such as those described above. At a fundamental level, we are interested in understanding the nature of metal–silicon (and other metal–element) bonds, detailing the properties that give rise to the unusual reactions that have been discovered. You will generate and test computational models that can help us draw reaction coordinate diagrams such as the one shown below, which is for a related reaction where carbon dioxide is transformed to carbon monoxide.



Computational work of this sort provides a great opportunity to formulate and test new chemical questions, understand structure and bonding at a deeper level, and learn new ways to use computers to give chemical insights.

What Will You Do?

This project involves substantial computational work and requires a good knowledge of organic chemistry (through CHEM 234). You will learn how to use density functional theory (DFT) as your primary technique and will spend considerable time interacting with other researchers to identify problems that your techniques are well-suited to solve.

If you are interested in working on this project, please do the following:

- **Set up an appointment with Dani to meet with both of us and discuss our research.**
- **Talk with Emma Watson or Zach DiNardo, who have worked on a collaborative computational project in our laboratories.**