2019 version

APPLICATION
Summer Undergraduate Research Experience (SURE)
SFA College of Sciences and Mathematics

SURE is a mentoring research experience for the summer during which an undergraduate conducts a research project. Proposed projects should develop research skills through participating in research or contributing to a larger research project. This is an opportunity to give undergraduates a transformative learning experience that will develop some of the skills needed for professional success after graduation.

Undergraduate research projects may involve:

- developing soft skills (critical thinking, problem-solving, adaptability, quantitative reasoning, communication, personal and time management, professionalism, collaboration, and responsibility),
- identifying and utilizing relevant previous work in support of a research project,
- identifying and utilizing appropriate methodologies to address a research question or creative objective,
- meeting the relevant field's standards for the responsible conduct of research, and effectively navigating challenges that arise in the research process,
- working collaboratively with other researchers, demonstrating effective communication and problem-solving skills,
- presenting the research effectively in a conference setting, writing a manuscript, and
- reflecting constructively on their research experience, identifying what was learned, personal strengths and opportunities for growth, and how the experience informs their future educational and career goals.

SURE experience requires that:

- the recipient student be paired with a faculty member for the research experience,
- the recipient student spend ~ 10-12 hours per week on research for a summer term and being present on campus or in the field for the duration of the term,
- mentoring an assigned student recruited by college initiative for underrepresented groups (if applicable),
- the recipient student attend weekly research meetings during the 2nd semester of the summer term with other SURE awardees to discuss topics such as making a research poster, maintaining a research notebook and safe practices, research ethics, and executing a literature background review,
- the faculty recipients to lead the discussions for at least one of the weekly meetings (if applicable),
- the recipient student create a research poster by the end of the SURE,
- the recipient student present research orally to the other recipients at the end of the SURE, and
- the recipient student submit a summary report of project results, grant application based on results, or professional publication to strengthen proposals for future funding.

Program Guidelines:

- This experience is intended to expand a college-wide undergraduate research program.
- The SURE initiative will take place during the 2nd semester of the summer term with weekly meetings with other recipients on Tuesday afternoons; however, projects may start prior to this time.
- Applications are due in the Dean's office by January 25, 2019. Notification of awards will occur by February 25, 2019.
- Faculty members will receive a $1,300 stipend.
- Student receive a $500 scholarship applied to their fall tuition bill.
- Up to $500 is available for supplies. Recipients are encouraged to request matching funds from their department.

2019 version

Faculty Member: J. Brannon Gary **Faculty ID:** 20290969

Department: Chemistry and Biochemistry **Faculty Email:** garyjb@sfasu.edu

Have you previously received a SURE award? Yes **If yes, when?** Summer 2018

If yes, how did you disseminate results from previous awards (successfully published a paper or obtained a grant, submitted paper or grant based on results, presented results at external conference, etc.):

Submitted a two year external grant with a total budget of $55,000, a manuscript is also currently in preparation and will hopefully be submitted in the May to August

Student's Name: Su Sandi **Student ID:** 20263789

Major: Chemistry **Student Email:** sandis@jacks.sfasu.edu

Have you previously received a SURE award? No **If yes, when?** N/A

Proposed SURE Project

Title of proposed SURE project: Bioinspired iron catalysis for the oxidation of carbon-hydrogen bonds

Description of proposed project (describe the scope of the project, including specific objectives):

The modern chemical industry is based upon the selective oxidation of highly reduced carbon feedstocks (oil, natural gas, and coal) to produce desired products and materials. This proposal aims to develop new iron catalyst systems for the oxidation of organic substrates. The enzymatic utilization of iron-oxo species is the design template for these new catalysts. Developing new catalyst systems utilizing cheap iron-based systems as opposed to typical expensive metals would be a significant advancement in the field. The project aims are as follows:

Aim 1) Train the student in advanced synthetic techniques along with the isolation, purification, and characterization of complex organic molecules

Aim 2) Study iron catalyst systems using the ligands acquired in Aim 1

Aim 3) Analyze catalyst systems for chemical reactivity and substrate selectivity

Aim 4) Compile data and prepare manuscript for publication

Is this a new project or a continuation of a current project? If a continuation, what new work will be done as part of SURE?

This project was initially started by Randy Romero (a student who received a SURE award last year). During his time, we were able to illustrate that the substitution of pyridine units with imidazole in our ligand shows significant changes in the chemo- and regio-selectivity of an iron-based catalytic reaction. These initial observations have allowed the faculty member to have preliminary results for submission of an external grant. In order to publish this work in a journal of high impact factor, studying the reaction on other substrates (other organic molecules to react with) and reaction conditions is required. Su will be expanding the scope of the previous work so that we can publish this work in an academic journal. Thus, by continuing this project, at least two undergraduate students funded through the SURE program should be co-authors on an academic journal publication.

Potential impact or significance of research:

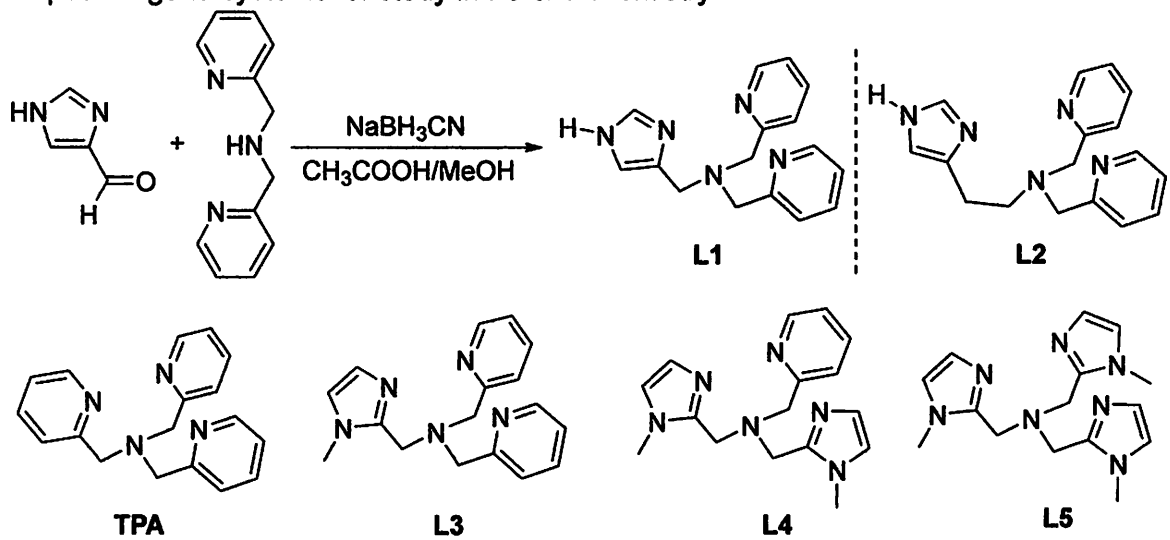
The selective oxidation of C-H bonds in organic molecules has been characterized as the "Holy Grail" of organometallic chemistry. Often these systems employ rare and expensive metals. Using biological enzyme systems as a roadmap, we hope to develop iron-based systems which can improve reactivity and cost associated with these systems. We

have developed an operationally simple protocol through careful choice of oxidant. Understanding the selectivity associate with this system is a key advancement in the field of bioinorganic and organic chemistry. The systems studied in this project will aid in the design of improved system in the faculty mentors lab and the field in general.

Research Design (approach/methodology):

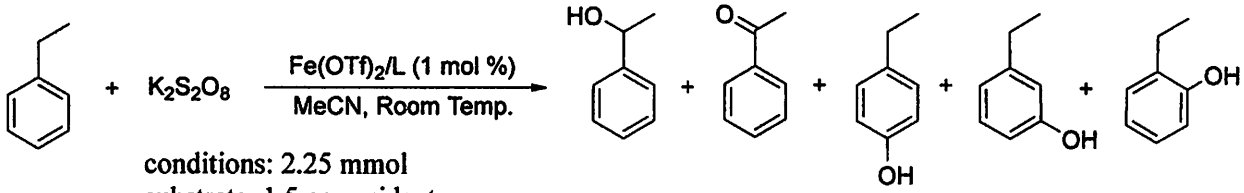
The project will utilize simple one-step synthesis of organic supporting ligands for iron systems (**Figure 1**). Importantly, this strategy allows for the student to be able to more quickly begin the study of organic oxidation reactions and limit the amount of time necessary for initial ligand synthesis. Su will specifically study the TPA ligand (commercially available) and the synthesized ligands **L3** and **L4** during the SURE project. Other ligands shown are potential later design scaffolds for post SURE studies.

Figure 1. Proposed ligand systems for study in Fe-oxo chemistry.



The catalytic reactions which will be studies are highlighted in **Figure 2**. Shown below are initial results with the TPA ligand (results by previous SURE student Randy Romero). We will expand the reactivity using **L3** and **L4** during this SURE project. We will also examine other substrates (chlorobenzene, toluene, and anisole).

Figure 2. Initial catalysis with potassium persulfate (relative product ratios are indicated below).



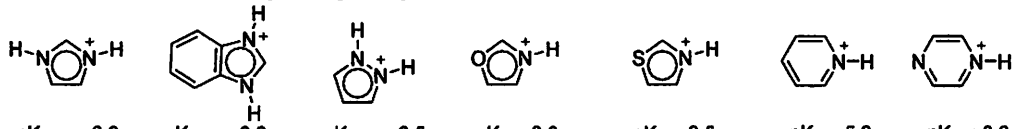
L = TPA	1.8	1.9	26.8	1	-

Literature review for project (must provide at least five peer-reviewed sources):

Histidine ligated enzyme systems have long been targets for synthetic model systems in bioinorganic chemistry, along with synthetic systems for organic reactivity. For example, the coordination sphere of a non-heme enzymatic system can be modeled using multidentate pyridine or amine ligands (Figure 2).[1-13] Pyridine is a logical substitute for imidazole given its ease of synthesis, similar basicity, commercial availability, and the large body of known inorganic chemistry with pyridine ligands. In contrast, relatively little work with imidazoles has been reported. Even in these sparse examples, the imidazole nitrogen is often alkylated, precluding the study of deprotonation and its resultant effect on reactivity.[9,14,15] This is likely the case because *N*-alkylation is required for C2 lithiation with *n*-butyllithium, a well-known synthetic strategy to incorporate imidazole into

multidentate ligands.[2] Imidazole is the main *N*-based ligand utilized in biological metalloenzyme systems and is unique in regards to common aromatic heterocycles in that it possesses a relatively basic ligating nitrogen (Figure 3). The unique basic properties of imidazole make it an attractive ligand scaffold. Furthermore, it has been shown that imidazole-metal bonds are surprisingly short, resulting in an increase in electron donation.[16] The limited steric bulk of imidazole ligation has been highlighted by the recently by formation of highly congested copper clusters.[17] More importantly the effect of steric bulk on chemical reactivity highlights a template for enhanced reactivity.[18,19]

Figure 3. Acidity of protonated nitrogen ligating heterocycles.



pK_{a1} = 6.9, pK_{a2} = 14.4 | pK_{a1} = 6.0, pK_{a2} = 12.8 | pK_{a1} = 2.5, pK_{a2} = 14.2 | pK_a = 0.8 | pK_a = 2.5 | pK_a = 5.3 | pK_a = 0.6

Significant progress has been made with Fe and Mn systems in the catalytic oxidation of C-H bonds,[8,20-28] epoxidation of olefins,[10,29,30] and dihydroxylation of olefins.[31] However, unlike the enzyme which have all been characterized in an S=2 spin state, most non-heme iron oxo model systems (ca. 90 %) have been characterized with an S=1 ground state (e.g., TPA – Figure 2). This spin state difference has been the rationale for the lower reactivity typically observed in model complexes.[32] By using strongly donating and sterically demanding ligands (e.g., H_3buea – Figure 2), C_3 symmetric trigonal bipyramidal oxo complexes which can reproduce the S=2 ground state have been reported; unfortunately the steric bulk has typically limited reactivity with external substrates.[15,33] The most successful S=1 system (fastest reactivity with C-H bonds) has been achieved with the Me_3NTB ligand.[34] In this system, the authors propose a low lying S=2 excited state which allows for enhanced reactivity. This result highlights the expected benefit of the proposed ligands below, as the benzimidazole is a more basic ligand than pyridine (Me_3NTB vs. TPA). This enhanced donation is proposed to contribute to labilization of a solvent molecule and promote the S=2 spin state for enhanced reactivity. Imidazole is more basic than benzimidazole and less sterically encumbered, providing an even more donating ligand to the metal. Both of these traits should provide easier access to the S=2 spin state and result in a more sterically accessible oxo fragment.

(1) Lee, Y.; Park, G. Y.; Lucas, H. R.; Vajda, P. L.; Kamaraj, K.; Vance, M. A.; Milligan, A. E.; Woertink, J. S.; Siegler, M. A.; Narducci Sarjeant, A. A.; Zakharov, L. N.; Rheingold, A. L.; Solomon, E. I.; Karlin, K. D. *Inorganic Chemistry* **2009**, *48*, 11297.
(2) Lynch, W. E.; Kurtz, D. M.; Wang, S.; Scott, R. A. *Journal of the American Chemical Society* **1994**, *116*, 11030.
(3) Sarkar, S.; Moon, D.; Lah, M. S.; Lee, H. I. *Bull. Korean Chem. Soc.* **2010**, *31*, 3173.
(4) Vankai, V. A.; Newton, M. G.; Kurtz, D. M. *Inorganic Chemistry* **1992**, *31*, 341.
(5) Wu, F. J.; Kurtz, D. M. *Journal of the American Chemical Society* **1989**, *111*, 6563.
(6) Wu, F. J.; Kurtz, D. M.; Hagen, K. S.; Nyman, P. D.; Debrunner, P. G.; Vankai, V. A. *Inorganic Chemistry* **1990**, *29*, 5174.
(7) Abu-Omar, M. M.; Loaiza, A.; Hontzeas, N. *Chemical Reviews* **2005**, *105*, 2227.
(8) Gunay, A.; Theopold, K. H. *Chemical Reviews* **2010**, *110*, 1060.
(9) Kryatov, S. V.; Rybak-Akimova, E. V.; Schindler, S. *Chemical Reviews* **2005**, *105*, 2175.
(10) Lane, B. S.; Burgess, K. *Chemical Reviews* **2003**, *103*, 2457.
(11) Meunier, B.; de Visser, S. P.; Shaik, S. *Chemical Reviews* **2004**, *104*, 3947.
(12) Ortiz de Montellano, P. R. *Chemical Reviews* **2009**, *110*, 932.
(13) Solomon, E. I.; Brunold, T. C.; Davis, M. I.; Kemsley, J. N.; Lee, S.-K.; Lehnert, N.; Neese, F.; Skulan, A. J.; Yang, Y.-S.; Zhou, J. *Chemical Reviews* **1999**, *100*, 235.
(14) Que, L. *Accounts of Chemical Research* **2007**, *40*, 493.
(15) Puri, M.; Que, L. *Accounts of Chemical Research* **2015**, *48*, 2443.
(16) Citek, C.; Gary, J. B.; Wasinger, E. C.; Stack, T. D. P. *Journal of the American Chemical Society* **2015**, *137*, 6991.
(17) Gary, J. B.; Citek, C.; Brown, T. A.; Zare, R. N.; Wasinger, E. C.; Stack, T. D. P. *Journal of the American Chemical Society* **2016**, *138*, 9986.
(18) Citek, C.; Lin, B.-L.; Phelps, T. E.; Wasinger, E. C.; Stack, T. D. P. *Journal of the American Chemical Society* **2014**, *136*, 14405.
(19) England, J.; Guo, Y.; Van Heuvelen, K. M.; Cranswick, M. A.; Rohde, G. T.; Bominaar, E. L.; Münck, E.; Que, L. *Journal of the American Chemical Society* **2011**, *133*, 11880.
(20) Bigi, M. A.; Reed, S. A.; White, M. C. *Nature Chemistry* **2011**, *3*, 216.
(21) Bigi, M. A.; Reed, S. A.; White, M. C. *Journal of the American Chemical Society* **2012**, *134*, 9721.
(22) Chen, M. S.; White, M. C. *Science* **2007**, *318*, 783.

(23) Chen, M. S.; White, M. C. *Science* **2010**, *327*, 566.
(24) Gormisky, P. E.; White, M. C. *Journal of the American Chemical Society* **2013**, *135*, 14052.
(25) Vermeulen, N. A.; Chen, M. S.; Christina White, M. *Tetrahedron* **2009**, *65*, 3078.
(26) White, M. C. *Science* **2012**, *335*, 807.
(27) Nam, W. *Accounts of Chemical Research* **2007**, *40*, 522.
(28) Nam, W.; Lee, Y.-M.; Fukuzumi, S. *Accounts of Chemical Research* **2014**, *47*, 1146.
(29) Murphy, A.; Pace, A.; Stack, T. D. P. *Organic Letters* **2004**, *6*, 3119.
(30) Terry, T. J.; Stack, T. D. P. *Journal of the American Chemical Society* **2008**, *130*, 4945.
(31) Chow, T. W.-S.; Wong, E. L.-M.; Guo, Z.; Liu, Y.; Huang, J.-S.; Che, C.-M. *Journal of the American Chemical Society* **2010**, *132*, 13229.
(32) Wilson, S. A.; Chen, J.; Hong, S.; Lee, Y.-M.; Clémancey, M.; Garcia-Serres, R.; Nomura, T.; Ogura, T.; Latour, J.-M.; Hedman, B.; Hodgson, K. O.; Nam, W.; Solomon, E. I. *Journal of the American Chemical Society* **2012**, *134*, 11791.
(33) Cook, S. A.; Borovik, A. S. *Accounts of Chemical Research* **2015**, *48*, 2407.
(34) Seo, M. S.; Kim, N. H.; Cho, K.-B.; So, J. E.; Park, S. K.; Clémancey, M.; Garcia-Serres, R.; Latour, J.-M.; Shaik, S.; Nam, W. *Chemical Science* **2011**, *2*, 1039.

Project timeline (activity/task and time to complete):

This research project is for the student's completion of the degree requirement for the B.S. in chemistry CHE 275, 475, and 470 sequence.

Fall 2018 (CHE 275 class)– original research proposal developed

Spring 2019 – (Aim 1) ligand synthesis and initial catalysis reactions to set up SURE experience

Summer 2019 (SURE) – (Aim 2 and 3) expansion of catalytic reactions (1 week per substrate highlighted in methodology)

Fall 2019 – (Aim 4) Preparation of manuscript

Spring 2020/Fall 2020 (CHE 475) – Use data from SURE to strive toward improved future ligand designs

Description of research and professional skills that the student will develop from the project:

The research will allow for training in significant chemistry skills not presented in typical course sequences. The student will perform organic synthesis and learn skills associated with the isolation and purification of complex organic molecules. The student will be exposed to advanced compound characterization through NMR spectroscopy. The student will gain insights into the terms and principles associated with catalytic reactions. The student will also gain experience in the analysis of complex reaction product mixtures using gas chromatography methods with flame ionization detection. The student will learn problem solving skills and data analysis associated with research.

Description of the involvement and activities that the student and mentoring faculty will have in this project:

The faculty mentor and student will both be present for the entire 5-week period. The faculty member will work with the student in the laboratory to train the student in proper laboratory techniques. Special care will be taken to insure safe laboratory practices. Specifically, the faculty member will help the student with performing laboratory experiments, the operation of instruments, and the analysis of results to maximize the amount of useful data and experiments which can be performed in this 5-week period.

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Description of how you will disseminate results from the project:

The project results will be disseminated in multiple forms. First, the data will be presented in a poster presentation associated with the SURE summer program. Second, the work will also be submitted to the Undergraduate Research Conference (URC) at SFASU and with an abstract submission for presentation at the Texas Academy of Science meeting to be held next year at SFASU. Finally, this work will be compiled and written up for submission to an academic peer-reviewed journal. Forums such as Inorganic Chemistry or ACS Catalysis would be target journals although journal choice could be modified to higher or lower impact journals depending on the novelty of the results obtained. Also, this work will be presented as a part of the student's research project for the CHE 275, 475, and 470 research sequence in fulfillment for the degree requirement for the B.S. degree at SFASU.

Budget ($0-$500 with justification):

The $500 supply budget will be used to purchase ligand precursors required for the synthesis of the desired ligands. These funds will be supplied by the department.

Amount requested for supplies from SURE: $ 0.00

Amount requested for supplies from department: $ 500.00

Amount department will fund faculty stipend: $ 0.00

Amount department will fund student stipend: $ 0.00

Chair approval: _____

Chair Signature

I have reviewed and agree to fulfill the expectations of the SURE award.

_____

Student Signature

_____

Faculty Signature

For internal purposes only:

Proposal Awarded _____ Proposal not award_____ Amount awarded: _____

Accounts to be used for award:_____