

Title

ADVANCING AUTOMATED REACTION DISCOVERY FOR COMPLEX CHEMICAL SYSTEMS INVOLVING IONIC AND OPEN-SHELL SPECIES

Abstract

Chemical reaction networks (CRNs) are essential in many fields, such as designing chemical process, building accurate simulation models for reactive systems, and designing new catalysts. A minimal CRN is composed of all intermediates and reaction rates for the reactions connecting all physically relevant species. Although conceptually simple, elucidating CRNs and establishing rate information for specific transformations are typically costly activities that are only performed retrospectively as part of design and discovery process. Computational transition state (TS) characterizations provide a potential avenue for exploring reaction mechanisms and rationalizing the kinetics of chemical reactions with minimal experimental calibration. For small reactants with a handful of competing reaction pathways, TS localization could be considered a solved problem. However, computational cost remains a bottleneck for reactions involving large systems or when exploring a deep CRN. To address this problem, our group has developed an automated reaction exploration program, Yet Another Reaction Program (YARP), to reduce the computational cost of exploring CRN by 100-fold to the state-of-the-art. However, YARP still has some obstacles in handling some conformation-sensitive reactions, such as Diels-Alder reaction, and other ring-formation reactions with distorted structures. Here, the conformational sampling method with a machine learning classifier is applied to enhance the reaction coverage and the convergence of TSs. Although YARP has shown robust performance when applied to closed-shell neutral organic systems, reactions involving open-shell compounds present distinct algorithmic challenges. To handle a more complicated system, YARP has been extended to describe the reactivity of ionic and open-shell system by expanding elementary reaction steps (ERS), applying solvation models, and accommodating alternative levels of theory when localizing TSs. These method development activities have been performed in the context of three case studies involving radical and ionic compounds. The first project is a biomass process to convert tetrahydrofuran (THF) into ketohydroperoxide (KHP) where the asymmetric formation of alpha and beta products has been an outstanding puzzle. Through this work, this process has been elucidated by identifying new chemical reactions by using different enantiomers of key intermediates. The next project is to extend YARP into a more complicated chemical system, Li-carbonate electrolyte degradation where there is still major debate regarding the role of competing lithiated ring-opened intermediates. In this study, YARP has been successfully applied to describe the reactions within this intricate system, encompassing closed-shell, anionic, cationic, and open-shell chemicals. By incorporating the principles of Dijkstra's algorithm, I have developed a most state-of-art CRN of lithium carbonate electrolyte and effectively addressed

the challenges posed by existing studies. The third project is selenium dioxide catalyzed polymerization of the conductive polymer via Riley oxidation. In collaboration with experimental chemists, we have provided evidence of proposed mechanisms of this process via both computational and experimental approaches. By identifying the TSs and calculating their activation energies, I successfully explained the reactivity difference between two structurally similar chemicals. The various applications and accuracy in bridging computational methods with experimental validation, ultimately advancing our understanding of complex reaction systems by YARP methodology.