Avis favorable

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Campagne 2020 Contrats Doctoraux Instituts/Initiatives

Proposition de Projet de Recherche Doctoral (PRD)

Appel à projet ISim - Initiative Sces et ingénierie moléculaires 2020

Intitulé du Projet de Recherche Doctoral : Low Valent Metals : Organometallic Reactivity (LoVaMOR)

Directeur de Thèse porteur du projet (titulaire d'une HDR) :

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Unité de Recherche :
Intitulé : Institut Parisien de Chimie Moléculaire
Code *(ex. UMR xxxx)* : UMR 8232

ED406-Chimie Moléculaire Paris Centre

Ecole Doctorale de rattachement de l'équipe & d'inscription du doctorant :

Doctorants actuellement encadrés par le directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 0

Co-encadrant :

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Unité de Recherche :
Intitulé : Laboratoire de Chimie Théorique
Code *(ex. UMR xxxx)* : UMR 7616

ED388-ChimiePhysiqueChimieAnalytique ParisCent

Ecole Doctorale de rattachement : Ou si ED non Alliance SU :

Doctorants actuellement encadrés par le co-directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 1, 2017, 30%

Cotutelle internationale : ☒ Non ☐ Oui, précisez Pays et Université :

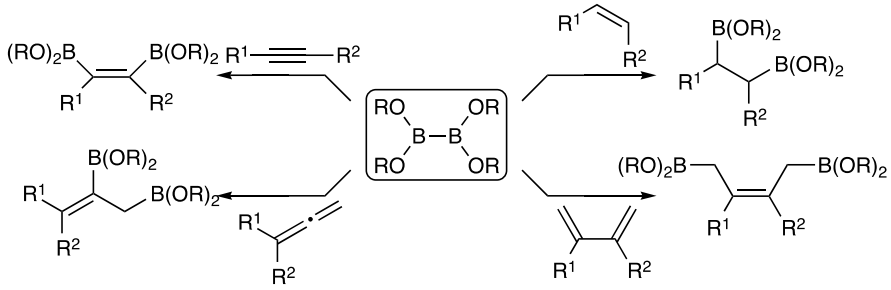
Description du projet de recherche doctoral *(en français ou en anglais)*

3 pages maximum – interligne simple – Ce texte sera diffusé en ligne

Détailler le contexte, l'objectif scientifique, la justification de l'approche scientifique ainsi que l'adéquation à l'initiative/l'Institut.
Le cas échéant, préciser le rôle de chaque encadrant ainsi que les compétences scientifiques apportées. Indiquer les publications/productions des encadrants en lien avec le projet.
Préciser le profil d'étudiant(e) recherché.

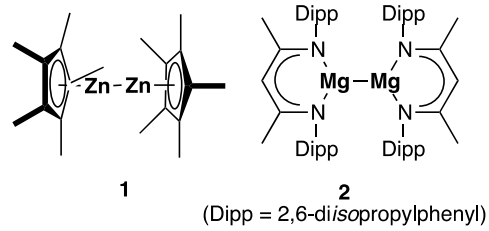
Low Valent Metals: Organometallic Reactivity (LoVaMOR)

Main-group organometallic compounds presenting a **metal–metal bond** are well known when the metal is an element of the group 13. Particularly diboron compounds, considered for a long time as structural curiosities, have found during the past decade widespread applications in organic and organometallic chemistry,[1] especially in the area of the multiple carbon-carbon bonds functionalization (Scheme 1).[1,2] Analogous dialuminum reagents have also been known for a long time[3] and have raised a considerable theoretical interest,[4] but have found so far less applications in organic synthesis.[5]



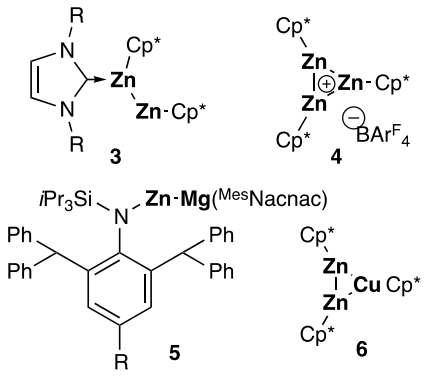
Scheme 1 : Some applications of diboron compounds

On the other hand, homologous main group dimetallic compounds **presenting a Zn–Zn or a Mg–Mg bond have been discovered more recently.** In 2004, Carmona reported[6] the first preparation and characterization of compound **1**, a molecular organometallic complex bearing a Zn(I) functionality and a Zn-Zn bond. Later, Jones reported in 2007 the first analogue Mg(I) complex **2** (Scheme 2).[7] The M-M bonding was described by theoretical chemistry, in particular the M–M bond length, the bond dissociation energy (BDE) and the electronic structure of the bond (ionic or covalent bond, orbital contributions).[8] For instance, complexes **1** and **2** exhibit a strongly covalent bonding involving the metal's orbitals (BDE of around 60 kcal.mol^{-1} and Zn-Zn distance of 2.331 A in complex **1**).[6,9] These two dimetallic complexes opened a totally new and very interesting research area, devoted to the design, preparation, characterization and theoretical understanding of various molecular complexes bearing a M–M bond where M is a main group metal at a low oxidation state.[8] For example, species presenting a Zn–Zn bond with different substitution pattern on each Zn atom have been reported (Scheme 3), among them the dizinc(I) carbene complex **3**[10], the trizinc cation **4** (where each Zn-atom presents a formal oxidation state of 1,33)[8]. The dissymmetry caused by the ligands in LM-ML' (**3**) affect the nature of the M–M bonding as it changes the electronic distribution between the two metal centers and in consequence the properties and thus the reactivity of the species. Rationalizing by theory the effect of ligands on the nature of M–M bonding seems mandatory to understand the reactivity of these complexes on route to applications. Conversely, mixed low valent complexes were also described, bearing a Zn(I)–Mg(I) functionality as **5**[11] or a Zn(I)–Cu(I) one as **6**[8]. In the case of mixed M–M' bond (as in **5** and **6**) as well as in the case of trimetallic species (i.e. **4**), traditional electronic descriptors such as oxidation degrees are no more unequivocally determined. In such species, an accurate description of the M–M bond is yet to be established in terms of electronic structure[12] and thus modelling the electronic properties of these dimetallic complexes remains a field to be invested from a theoretical view point.



1 **2**
(Dipp = 2,6-di*iso*propylphenyl)

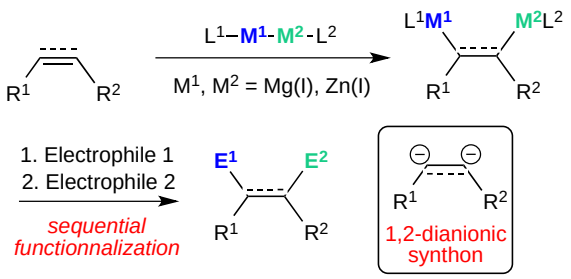
Scheme 2 : Seminal Zn–Zn and Mg–Mg complexes



Scheme 3 : Notable recent Zn–Zn and mixed Zn-M complexes

The above-selected examples showcase the remarkable recent diversity and surprizing stability of di- or trimetallic complexes with Zn(I) and/or Mg(I) metal centers. Surprisingly however, by contrast with the dibora species, **almost nothing is known about the reactivity of such low valent molecular main-group organometallic species**, despite their relative ease of access.

The proposed research project is focused on the examination of the reactivity of such low-valent bimetallic compounds, **with a particular interest allowing for the functionalization of C–C multiple bonds**. Our aim will be to develop a straightforward approach to 1,2-bimetallic alkenes and alkanes through the addition of M–M species onto alkynes and/or alkenes (Scheme 4). This approach will be tackled through an **intertwined synthetic and theoretical approach** in order to fully characterize the chemical potential of these uncommon dimetallic low valent reagents. For instance, only one example of addition across multiple C–C bond was reported, involving the reaction of dimagnesium compound **2** with 1,1-diphenylethylene.[13] Here however, the addition was found to be *reversible* and thus non-synthetically useful. We anticipate that tuning the M–M versus M–Ligand bonding using for instance carbene ligands would represent a valuable way to control the addition process and displace the equilibrium toward the desired side of the equilibrium, as it was demonstrated[14] for dialuminum reagents. The introduction of ligands to tune the selectivity could also pave the way for the development of asymmetric variants that have not been considered so far. Notably, chiral analogues of 3 prepared from readily accessible chiral NHC ligands could be particularly well suited and would represent a real breakthrough in this chemistry.

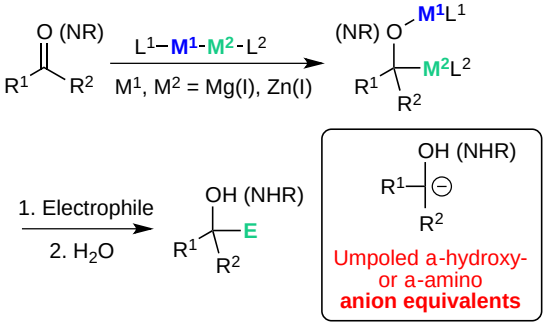


Scheme 4 : Dimetallation of alkenes or alkynes and sequential functionalizations

Depending on the nature of the starting organometallic complex and of the attached non-innocent ligands, sequential functionalizations will be envisioned, leading to **polyfunctionalized alkenes or alkanes.**

It should be noted that whereas the known dimetallic complexes are difficult to isolate, they are surprisingly easy to prepare. We will thus focus on **one-pot approaches, without any isolation of the mixed dimetallic structures**. This will be carried out with a synergetic approach between computational study of reaction mechanisms and experimental development of synthetic procedure. The structure, analysis of the bonding and mechanisms of the surmised dimetallic species will be studied through computational study and compared to experimental results. The interplay between experiment and theory (answers/requests/questions) in real time is key to allow a real progress of this study.

In another field of application, the reducing ability[15] of these complexes will also be examined, in order to define new and selective strategies involving the **controlled** reduction of carbonyl or imine functions. A particularly interesting prospect related to the controlled reduction of aldehydes, ketones or imines is the possibility to access **umpoled α-hydroxy- or α-amino anion equivalents** (Scheme 5). The expertise of the theoretical group on the regiocontrolled conjugate addition of dienone catalyzed by Cu–Zn bimetallic complex will be highly beneficial for this part.[16] Indeed, different active species and their associated mechanisms were studied computationally and it



Scheme 5 : Reduction of carbonyls or imines

was demonstrated that the observed selectivity relied on the distinct roles played by the two metals (Zn and Cu) of the bimetallic species. The quantitative analyses offered by computational study are thus a powerful tool to understand the factors that govern the selectivity issues. Here again, the use of chiral NHC-complexes would open a route to chiral *disubstituted*[17] α-hydroxy- or α-amino anions and thus to enantioenriched tertiary alcohols or amines.

This project involves two partners, one for the organometallic synthetic component, (Pr. Fabrice Chemla and Dr. Alejandro Perez Luna, team ROCS, IPCM) and one for the computational component (Dr. Stéphanie Halbert and Pr. Hélène Gérard, team IOC, LCT). The *Réactivité Organométallique et Catalyse pour la Synthèse* (ROCS) team from IPCM (UMR 8232) has recognized expertise for the preparation, handling and reactivity studies of main group organometallic reagents, including elementometalation processes[18] and bimetallic reagents.[19] The *Inorganic and Organometallic Chemistry* (IOC) team from LCT (UMR 7616) has an expertise on the mechanisms and selectivity in reactions implying copper, zinc species[16] as well as RMgX Grignard reagents[20] in collaboration with experimental groups. The PhD student will thus benefit from the state-of-the-art expertise of the LCT members in terms of computational as well as interpretative methodologies, allowing its members to deal confidently with the complexities associated to the non-classical oxidation degrees and bond types involved in this project.

Applicant profile: the Ph.D. project will be experimentally-driven, with a constant interplay between experiments and theory. Thus experimental skills in organic and/or organometallic chemistry are required, as well as a consistent curiosity in theoretical chemistry and its tools.

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