Abstract Book

Young Researchers Symposium

CBOND2024

Amsterdam

23 SEPTEMBER 2024

4TH EUROPEAN SYMPOSIUM ON CHEMICAL BONDING

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Welcome to CBOND2024

On behalf of the Organizing Committee, it is a pleasure to welcome you to the 4th European Symposium on Chemical Bonding (CBOND2024), which takes place on 23–27 September 2024 at the O|2 Building on the campus of the Vrije Universiteit Amsterdam.

The European Symposium on Chemical Bonding an international conference series that started in 2016 with meetings being held across Europe.

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The series is one of the key activities of the European Committee for Chemical Bonding to promote science and research in the realm of chemical bonding theory.

We wish you a wonderful stay in the beautiful city of Amsterdam and a pleasant and inspiring conference, with many interesting discussions, at Vrije Universiteit Amsterdam.

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Program

Monday 23 September

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9:45–10:00	**Jochen Eeckhoudt**
10:00–10:15	**Davide Zeppilli**
10:15–10:30	**Steven Beutick**
10:30–11:00	Coffee Break
	Chair: Angelina van Dam
11:00–11:15	**Franz Thiemann**
11:15–11:30	**Siebe Lekanne gezegd Deprez**
11:30–11:45	**Katarina A. Ćeranić**
11:45–12:00	**Emma L. Hollis**
12:00–12:15	**Soumya Ranjan Dash**
12:15–12:30	**Bin Wang**
12:30–13:30	Lunch
Chair	*Siebe Lekanne Deprez*
13:30–13:45	**Aleksandra L. Ptaszek**
13:45–14:00	**Murillo H. Queiroz**
14:00–14:15	**Sonja S. Zrilić**
14:15–14:30	**Yuman Hordijk**
14:30–14:45	**Sizhuo Yu**
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15:00–15:30	Coffee break
Chair	*Yuman Hordijk*
15:30–15:45	**Joan Grèbol-Tomàs**
15:45–16:00	**Eveline Tiekink**
16:00–16:15	**Miguel Gallegos**
16:15–16:30	**Inés Sánchez-Movellán**
16:30–16:45	**Thakur Rochak Kumar Rana**
16:45–16:55	Closing
16:55–18:30	Drinks and Pizza

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5. **Franz Thiemann |** Trends in the Reactivity of Pentacyclic Ether Derivatives on Silicon and Germanium Surfaces Revealed by Energy Decomposition Analysis for Extended Systems
6. **Siebe Lekanne Deprez |** Effect of Chalcogen Atom Size on Hydrogen Bond Strength in Amide-based Linear Polymers
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Aromaticity of Adsorbed π-Electron Systems

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The interactions between polycyclic hydrocarbons (PCHs) and metal surfaces are a crucial factor in the performance of organic electronic devices. Therefore, a deeper understanding of such metal-organic interfaces is necessary. An important chemical concept for the description of PCHs is aromaticity. Over the past years, numerous aromaticity indices have been proposed, which can be broadly divided into four categories: energetic, geometric, electronic, or magnetic. Upon interaction of the π-electron system of a PCH with a metal substrate, the aromaticity of the PCH can, however, be significantly altered. To evaluate this effect, we investigated a set of 11 non-alternant and 11 alternant PCHs adsorbed on a Cu(111) surface. We previously showed that these systems exhibit different strengths of interactions ranging from physisorption to weak and strong chemisorption.[1]

Using density functional theory with periodic boundary conditions, we were able to use geometric and electronic aromaticity indices to investigate the aromaticity of the adsorbed molecules. Comparison with their gas phase aromaticity showed significant changes upon adsorption. Those changes in aromaticity seem to be a promising extension to the usual interfacial properties, addressing effects not covered by them and contributing to a better understanding of metal-organic interfaces.
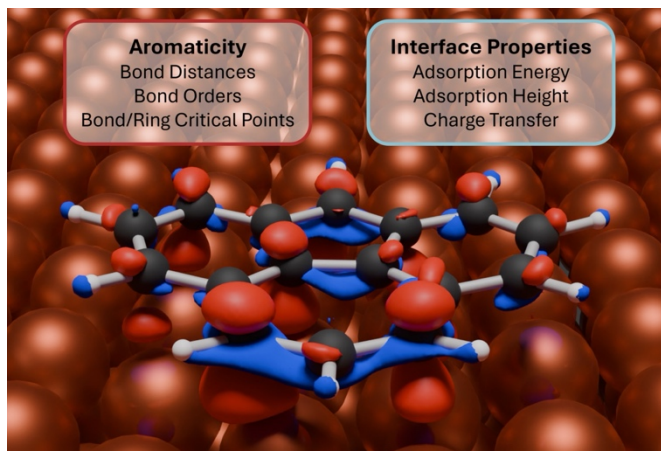
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# Aromaticity Descriptors under Isotropic Pressure

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In the past decades, the interest in high pressure chemistry has taken up again, bringing with it developments in quantum mechanical models for describing pressure at the single molecular level. While some of these, such as X-HCFF[1], start from mechanochemical principles, others, such as GOSTSHYP[2], apply the pressure directly through the Hamiltonian operator. These models have allowed for the evaluation and analysis of many atomic and molecular properties[3] and are now used to study the elusive aromaticity concept, which has only been sparsely investigated under pressure[4,5]. In our work, we consider some of the most widely used descriptors and indices for quantifying aromaticity and examine their behaviour under pressure for benzene, the archetypal aromatic system. We consider the effects of different pressure models and determine what causes changes in aromaticity, how they are meaningful and where they (dis)agree.
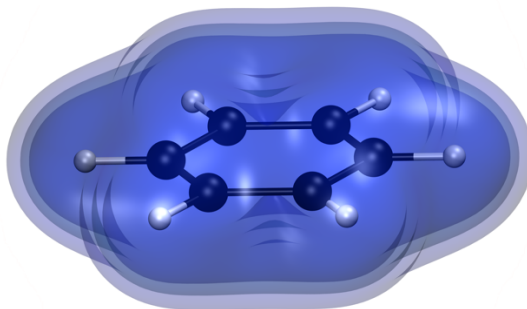
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# Radical Scavenging and Anti-Ferroptotic Molecular Mechanism of Olanzapine: Insight from a Computational Analysis

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Olanzapine is an antipsychotic drug which has been reported to suppress ferroptosis,[1] a recently discovered form of regulated cell death.[2] The ROS scavenging activity of olanzapine is investigated *in silico* using state-of-the-art DFT calculations (level of theory: (SMD)-M06-2X/6-311+G(d,p)//M06-2X/6-31G(d)). Indeed, this reactivity is linked to the therapeutic activity of many antipsychotic drugs and ferroptosis inhibitors.[3] In detail, the distinction between Hydrogen Atom Transfer (HAT) and concerted Proton Coupled Electron Transfer (cPCET) is elucidated for the most reactive sites of the studied molecule. An anti-ferroptotic cyclic mechanism is proposed for ferrostatin-1, a well-known ferroptosis inhibitor,[4] as well as for olanzapine, involving the oxidation of Fe^{II} to Fe^{III}, the quenching of hydroperoxyl radicals and the subsequent regeneration of the reactant (level of theory: M06/6-311+G(d,p),def2TZVP//M06/6-31G(d),LANL2DZ), paving the route to a molecular explanation of this complex biological process.
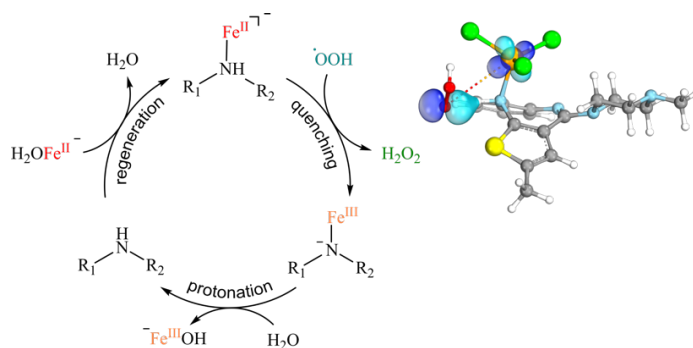
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Retro-Cope elimination of cyclic alkynes: reactivity trends and rational design of next-generation bioorthogonal reagents

Steven Beutick,[a,b] Song Yu,[a] Laura Orian,[b] F. Matthias Bickelhaupt,[a,c,d] Trevor A. Hamlin[a]

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The retro-Cope elimination reaction between dimethylhydroxylamine (**DMHA**) and various cyclic alkynes has been quantum chemically explored using DFT at ZORA-BP86/TZ2P. The purpose of this study is to understand the role of the following three unique activation modes on the overall reactivity, that is (i) additional cycloalkyne predistortion via fused cycles, (ii) exocyclic heteroatom substitution on the cycloalkyne, and (iii) endocyclic heteroatom substitution on the cycloalkyne. Trends in reactivity are analyzed and explained by using the activation strain model (ASM) of chemical reactivity. Based on our newly formulated design principles, we constructed a priori a suite of novel bioorthogonal reagents that are highly reactive towards the retro-Cope elimination reaction with **DMHA**.[2] Our findings offer valuable insights into the design principles for highly reactive bioorthogonal reagents in chemical synthesis.
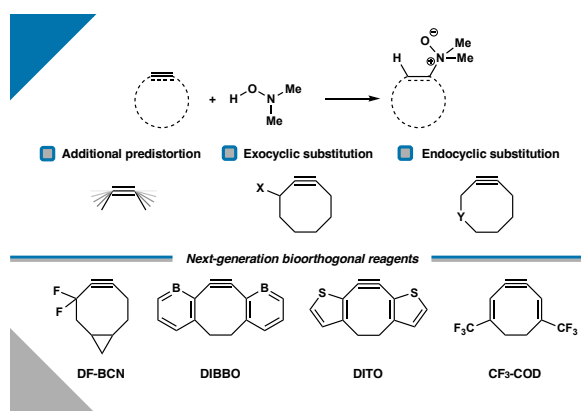
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Trends in the Reactivity of Pentacyclic Ether Derivatives on Silicon and Germanium Surfaces Revealed by Energy Decomposition Analysis for Extended Systems

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Organic functionalization has emerged as a promising way of tailoring surface properties of semiconductors to fit a wide range of applications. Especially silicon and germanium are of great interest due to their industrial relevance. Therefore, we analyzed the adsorption and ring-opening reaction of pentacyclic chalcogen alkyls with chalcogen atoms ranging from oxygen to tellurium using simulations. This extends our previous investigation of THF on silicon[1] to the germanium surface and the heavier chalcogen homologues. Following the dative bound state, subsequent ring-opening reactions were found to proceed via a nucleophilic back-side attack, similar to a molecular S_N2 reaction. We present data from periodic energy decomposition analysis[2] (pEDA) for precursor and transition state structures that reveal distinctive differences between silicon and germanium. Reaction energies and barrier heights exhibit a maximum at the sulfur derivative, with the lower barrier of THF being caused by the ring strain.
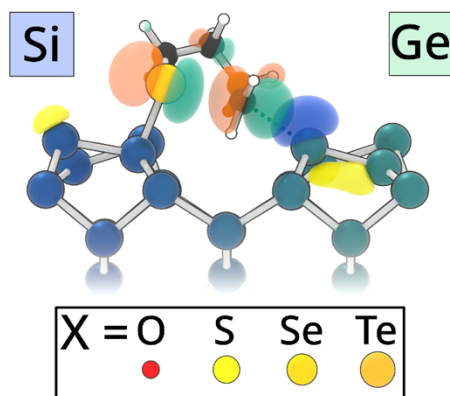
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Effect of Chalcogen Atom Size on Hydrogen Bond Strength in Amide-based Linear Polymers

Siebe Lekanne Deprez[a], Lucas de Azevedo Santos[a], Celine Nieuwland[a], David Almacellas[b], Jordi Poater[b,c], Pascal Vermeeren[a], Célia Fonseca Guerra[a]

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Supramolecular linear chains of urea, deltamide, and squaramide have the potential to form complex supramolecular structures due to their capability of forming hydrogen bonds[1], but what are the implications considering their sulfur and selenium analogues? Previous work with urea showed that substituting sulfur and selenium for oxygen leads to an unexpected increase in hydrogen-bond donor strength[2]. Our current work extends these insights to the supramolecular realm, utilizing dispersion-corrected density functional theory (ZORA-BLYP-D3(BJ)/TZ2P) to explore how these chalcogen substitutions influence hydrogen bonding in linear chains composed of urea, deltamide, and squaramide building blocks[3]. We reveal that as the chalcogen size increases, the larger chalcogen withdraws more charge from adjacent amino groups, amplifying the positive character of hydrogen donors and strengthening their interaction with negatively charged acceptors. This nuanced interplay of forces expands the toolkit for designing supramolecular assemblies with tailored properties.

Hydrogen-Bond Donor Capability
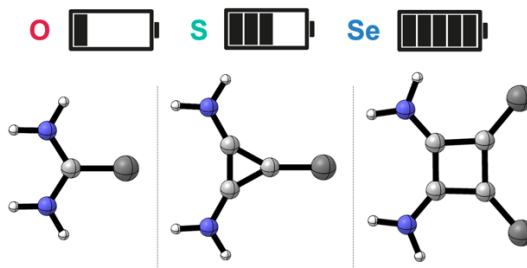
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Unravelling the changes in the geometries of sandwich compounds induced by cation-π interactions – a DFT study

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Ion-π interactions are important in numerous molecular systems. These interactions can be enhanced by the transition metal coordination of aromatic rings, which was previously show on anion-π interactions of benzene half-sandwich compounds,[1] as well as cation-π interactions of ferrocene.[2] In this work, we have studied structural changes in the geometries of three benzene sandwich compounds ($Cr(benzene)_2$, $Mo(benzene)_2$ and $W(benzene)_2$) upon the formation of cation-π interactions. Cation-π complexes of three benzene sandwich compounds with alkali and alkaline earth metal cations, as well as ammonium, were examined by the means of DFT calculations, employing the B3LYP density functional with def2-TZVP basis set. The studied sandwich compounds form stronger cation-π interactions than (uncoordinated) benzene, and these interactions are particularly strong for alkaline earth cations ($W(benzene)_2/Mg^{2+}$ interaction has the energy of -196.77 kcal/mol). The formation of these cation-π interactions induces several interesting changes in the geometries of sandwich compounds. Namely, the distance between aromatic rings in the sandwich ($d_{\pi-\pi}$, Fig. 1) is relatively constant whether or not cation-π interaction is formed. However, cation-π interactions induce the shortening of the $d_{M-\pi,top}$ distance (Fig. 1) and the lengthening of the $d_{M-\pi,bottom}$ distance (Fig. 1), and this effect gets more pronounced by the strengthening of cation-π interactions.
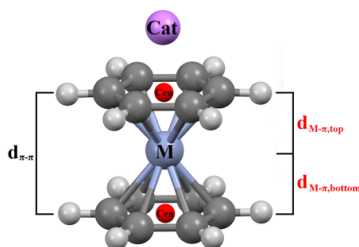

Fig. 1. Cation-π complex of a sandwich compound. **Cat** is for cation; **Cen** is for centroid; and **M** is for a transition metal: Cr, Mo or W.

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[1,n]-Metal Migrations for Directional Translational Motion at the Molecular Level

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We present carbon-to-carbon rhodium migrations as a new approach to mimicking the dynamic association that underpins directional translational molecular level motion displayed by biological systems such as DNA polymerase and myosins.[1] To date, artificial rotaxane or molecular walker systems which display controlled translational molecular level motion either utilise mechanical bonds and ratcheting mechanisms to achieve directional movement.[2] Or, for the walker systems that do not utilise a mechanical bond, the stepwise intervention of an experimentalist is required to achieve directionality.[3] The system detailed herein represents the first example of autonomous directional translational motion at the molecular level in a fully synthetic system that does not rely on mechanical bonds.
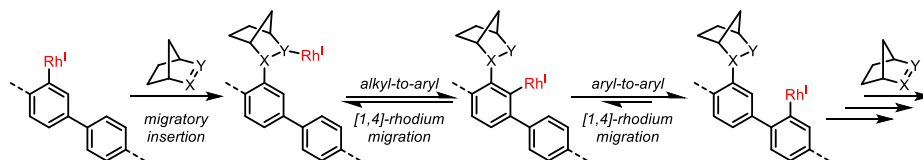

Figure 1: Three-step system using norbornene as a hydrocarbon chemical fuel (X=Y) and rhodium migrations for the directional translation of a rhodium centre along archetypal track 1,4-polypheneylene.

Upon a polyaromatic track, rhodium may be translated unidirectionally *via* repeating cycles of the following three-step process: incorporation of the strained hydrocarbon fuel norbornene (X=Y), followed by an alkyl-to-aryl rhodium migration, then an aryl-to-aryl rhodium migration. The incorporation of large norbornene groups onto various polyaromatic tracks has been shown to ratchet the system and achieve the directional translation of a rhodium centre over extended distances, without the requirement of a mechanical bond.

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Going where Experimentalists Fear to Tread: Computational Chemistry to the Rescue in Understanding XeO₃ Chemistry
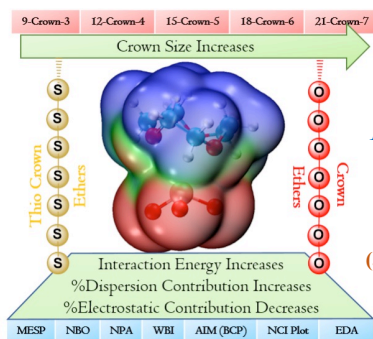
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The hazardous nature of XeO_3 makes computational studies an ideal means of exploring its new chemistry.[1,2] To enhance the stability of this highly explosive and shock-sensitive compound, DFT calculations were conducted to investigate its potential complexation with crown ethers and their thio (-S) and aza (-NR) analogues.[3,4] Interestingly, aza-crowns exhibited superior binding to XeO_3 compared to their oxygen and thio counterparts. However, while the binding affinity was observed to increase with the size of the crown ethers in the latter cases, aza-crowns showed a variable size preference, peaking with aza-15-crown-5 and decreasing thereafter. Significant contributions from secondary C-H…O interactions were found to strengthen the σ-hole-mediated aerogen bonding in these complexes. Additionally, a rare Xe…Xe interaction was observed to influence the coordination number of xenon in a 1:2 complex of 18-crown-6 with two XeO_3 molecules, resulting in a first-of-its-kind inverse sandwich complex for a noble gas compound.[5]
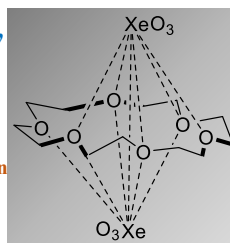
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The description of Atom and Bond Reactivity in the Language of Conceptual Density (Matrix) Functional Theory

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In the context of the growing impact of conceptual density functional theory (CDFT) as one of the most successful chemical reactivity theories, response functions up to second order have now been widely applied; in recent years, among others, particular attention has been focused on the analytic evaluation of these response functions and extensions to higher order have been put forward.[1] The traditional CDFT gives sharp definitions for a set of well-known but vaguely defined concepts such as chemical potential (electronegativity) and hardness/softness. In addition, it gives access to regioselectivity, electro-/nucleophilicity through local reactivity descriptors such as the Fukui function and (hyper)polarizability via a nonlocal (non)linear response function.[2-3] In our study, their performances are compared between the analytical approach with the wildly used finite difference approximation. In the same spirit of traditional CDFT, we further extended its matrix formalism called conceptual density matrix functional theory (CDMFT) for the description of the reactivity or property of chemical bonds in molecular systems. With the quantity defined in CDMFT, i.e., Fukui matrix, we illustrate that the derivative of bond order with respect to the number of electrons is closely related to the difference of force constant and bond distance between natural and ionized systems.[4]

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Ligand ^{1}H NMR Chemical Shifts as Accurate Probes for Protein-Ligand Interactions in Solution

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High-resolution 3D structural data is crucial for analysing guest-host systems in the context of drug discovery. While X-ray crystallography is a standard technique, it has limitations in capturing protein flexibility in solution.[1] NMR spectroscopy offers an alternative, providing insights not only into molecular dynamics but also into non-covalent interactions at atomic resolution. Of special interest is information encoded in the ^{1}H chemical shift (CS) which is sensitive to the presence of non-covalent interactions such as hydrogen bonds and CH···π contacts.[2,3] This research emphasises the use of ligand ^{1}H CSs as reporters for the binding site of small molecules with their target proteins. By comparing the experimental ligand ^{1}H CS values with those calculated from the X-ray structure using quantum mechanics methodology, we identify significant disagreements for parts of the ligand between the two experimental techniques. We show that quantum mechanics/molecular mechanics (QM/MM) molecular dynamics (MD) ensembles can be used to refine initial crystal structures resulting in a better agreement with experimental ^{1}H ligand CS values. Overall, our work highlights the value of ligand ^{1}H CS information for understanding and validating the interactions of ligands with their target proteins in solution, which can significantly benefit early-stage drug discovery.
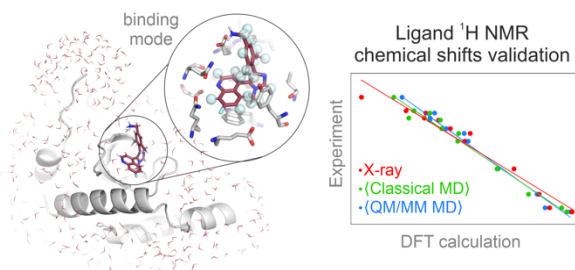
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H-Bonds between 1,3-Cyclopentadiene Derivatives and Water Clusters: Impact on Photochemical Ionization Pathways

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In this investigation we explore intermolecular interactions between 1,3-cyclopentadiene and its cyano derivatives and water clusters considering astrochemical conditions. The recent discovery of Aromatic Hydrocarbons (AHs) like 1,3-cyclopentadiene (CPD) and its cyano derivatives [1] in Taurus molecular cloud has spurred theoretical investigations into molecular clusters formation in space [2]. By using density-functional theory (DFT) and time-dependent DFT (TD-DFT), we examine the stability, H-bonding patterns, and ionization potentials of AH-water complexes. Key findings reveal that H-bonding (O-H···π and O-H···N) significantly influences the stability and ionization energies of these clusters.
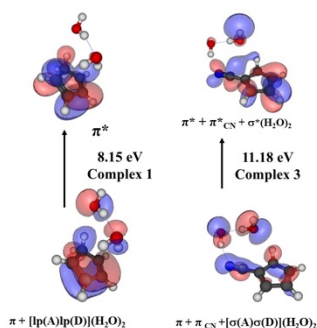

Figure.1. Molecular orbitals involved in the main CT transitions.

Our results show distinct electronic transitions and absorption properties of AH-water complexes under vacuum ultraviolet (VUV) radiation, crucial for understanding photochemical processes and molecular rearrangements in space. The research provides insights into the initial steps of AH formation and the dynamics of ionization processes influenced by H-bonding configurations.

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Nature of hydrogen bonds of coordinated glycine complexes with water

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Coordinated glycine can form three types of hydrogen bonds with a water molecule: NH/O involving complex's α-amino group as a hydrogen bond donor, O1/HO involving α-hydroxyl O1 oxygen of the complex as a hydrogen bond acceptor, and O2/HO involving complex's α-carbonyl O2 oxygen as a hydrogen bond acceptor. Cambridge Structural Database (CSD) search and quantum chemical calculations were done for various glycine complexes to evaluate the strength of their interactions with a water molecule.[1,2] Energy decomposition analysis was used to elucidate the nature of hydrogen bonds of different metal ion glycine complexes with a water molecule. Both perturbational (Symmetry Adapted Perturbation Theory, SAPT)[3] and variational (Localized Molecular Orbitals Energy Decomposition Analysis, LMO-EDA)[4] were deployed. The values of total interaction energies showed good agreement with CCSD(T)/CBS values. Energy decomposition analysis revealed that the electrostatic interaction is the leading attractive energy term, while orbital relaxation values are also significant. Effects of complex charge, metal oxidation number, complex coordination number, and metal atomic number on all decomposition terms were also evaluated.

Energy decomposition analysis

Nature of hydrogen bonds
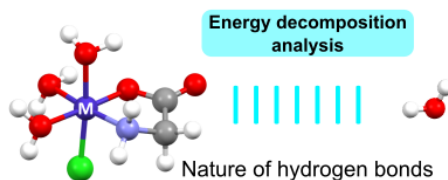
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Radical Addition Reactions:
Hierarchical *Ab initio* Benchmark and DFT Performance Study

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Benchmarking is an important topic in all of computational chemistry. It is the one way to figure out if your methodology is accurate and reliable for a given chemical system. In this talk I will talk about the do's and don'ts of our benchmark on radical addition reactions.[1] We used a hierarchical[2] series of *ab initio* methods (HF, MP2, CCSD, CCSD(T)) paired with a hierarchal series of Dunning basis sets with and without diffuse functions ((aug)–cc–pVDZ, (aug)–cc–pVTZ, (aug)–cc–pVQZ). Since we work with radical systems we transformed the HF ground-state wavefunctions into quasi-restricted orbital (QRO) reference wavefunctions to address spin contamination. Following extrapolation to the CBS limit, we determined that the energies from our highest- QRO–CCSD(T)/CBS+ level were converged with respect to the *ab initio* method and basis set, respectively. Our QRO–CCSD(T)/CBS+ reference data was used to evaluate the performance of 98 density functional theory (DFT) approximations for both energetics and key geometrical parameters of the stationary points.
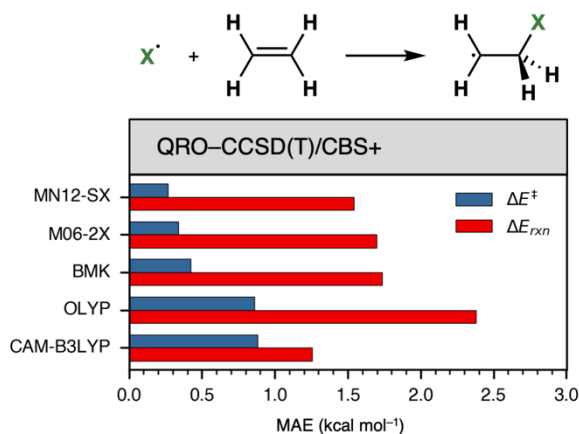
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Experimental Reconstruction of one-electron reduced density matrices

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The experimental determination of electronic behaviours has been an important counterpart to theoretical computations in chemistry. For example, X-ray diffraction measurements of crystals can be used to obtain the charge density and related chemical bonding information [1]. Beyond charge densities, the one-electron reduced density matrix (1-RDM), a one-particle complete description of el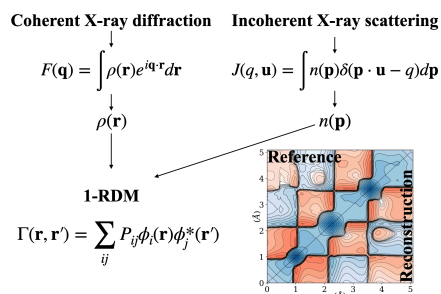ectrons, can also in principle be reconstructed from experiments. Starting with the work of Clinton [2], the 1-RDM reconstruction problem has been at the centre of the interplay between crystallography and quantum chemistry, namely the field of quantum crystallography [3,4]. We will briefly introduce the history of experimental reconstruction of 1-RDMs and its relation to charge density refinements and report our latest results of 1-RDM reconstruction from joint use of position and momentum space measurements [5-7]. In our approach, the restricted active space 1-RDM is fitted to the experimental data while necessary constraints such as symmetry and N-representability conditions are guaranteed using convex programming. A numerical validation is carried out on the (non-centrosymmetric) urea crystal using corrupted artificial data to assess the robustness and quality of this method. Finally, our latest results using actual experimental data will be briefly discussed.

Coherent X-ray diffraction

$$F(\mathbf{q}) = \int \rho(\mathbf{r})e^{i\mathbf{q}\cdot\mathbf{r}}d\mathbf{r}$$

$$\rho(\mathbf{r})$$

1-RDM

$$\Gamma(\mathbf{r}, \mathbf{r}') = \sum_{ij} P_{ij}\phi_i(\mathbf{r})\phi_j^*(\mathbf{r}')$$

Incoherent X-ray scattering

$$J(q, \mathbf{u}) = \int n(\mathbf{p})\delta(\mathbf{p}\cdot\mathbf{u} - q)d\mathbf{p}$$

$$n(\mathbf{p})$$

Figure 1: *A schematic illustration of experimental 1-RDM reconstruction. The figure on the lower right shows the reconstructed and reference 1-RDM on the O-C-N-H path of urea molecule in our numerical test.*

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Oxidation of Diorganochalcogenides by H_2O_2 in Aqueous Solution

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Sulfur and selenium redox chemistry plays a pivotal role in living beings. While the former is present in numerous proteins, peptides and metabolites, the latter is almost exclusively found in a few enzymes that are essential for homeostasis, such as glutathione peroxidases (GPxs).[1] GPxs prevent the buildup of damaging hydroperoxides species through a sophisticated Se(II)/Se(IV) redox equilibrium. Likewise, diorganochalcogenides display an analogous reactivity, although it is not fully clear which species is the active catalyst.[2-4] Further knowledge on the mechanism of the GPx-like activity of dialkyl and diaryl chalcogenides is very valuable, for an application as antioxidants and green catalysts in organic synthesis for the activation of H_2O_2.

Our theoretical investigation aims at modelling the reactivity of simple diorganochalcogenides in aqueous solution with H_2O_2. By means of a Density Functional Theory approach, we have studied the mechanism of oxidation of chalcogenides, as well as the equilibria mediated by solvent molecules. The role of the chalcogen and substituent effects as well as the relative trends have also been assessed. Based on our results, we suggest that hydroxy perhydroxy chalcogenanes are likely key intermediates in the redox process.
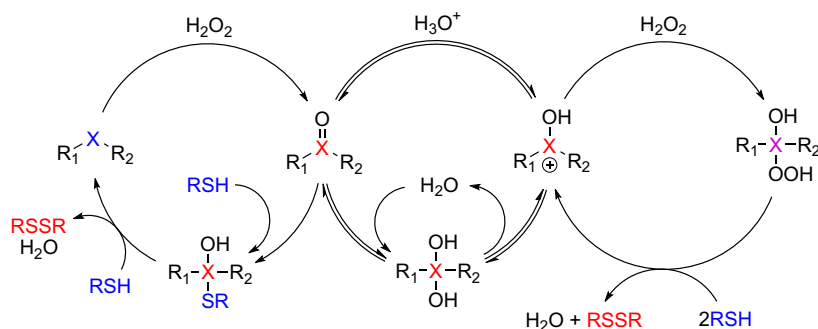
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Evaluating electronic aromaticity indicators from robust, cheap and error-free Hilbert-space partition schemes

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Aromaticity is a fundamental concept in chemistry that explains the stability and reactivity of many compounds by identifying atoms within a molecule that form an *aromatic ring*. Reliable aromaticity indices focus on electron delocalization and depend on atomic partitions, giving rise to the concept of an *atom-in-the-molecule* (AIM). Real-space atomic partitions present two important drawbacks: a high computational cost and numerical errors, limiting some aromaticity measures to medium-sized molecules with rings up to 12 atoms. This restriction hinders the study of large conjugated systems like porphyrins and nanorings. On the other hand, traditional Hilbert-space schemes are free of the latter limitations but can be unreliable for the large basis sets required in modern computational chemistry. This paper explores AIMs based on three robust Hilbert-space partitions – meta-Löwdin[1], Natural Atomic Orbitals (NAO)[2], and Intrinsic Atomic Orbitals (IAO)[3] – which combine the advantages of real-space partitions without their disadvantages. These partitions can effectively replace real-space AIMs for evaluating the aromatic character. For the first time, we report multicenter index (MCI) and I_{ring} values for large rings and introduce ESIpy, an open-source Python code for aromaticity analysis in large conjugated rings.[4]
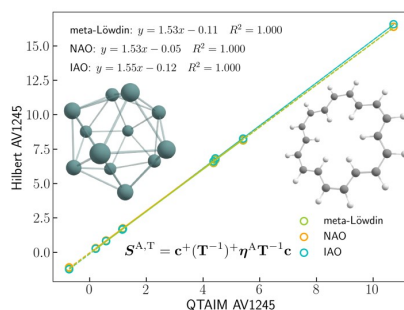
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# Origin of Catalysis in Cycloaddition Reactions of Tropone

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In this talk, we will dive into the origin of catalysis in cycloaddition reactions of tropone by using density functional theory calculations. We will focus on two general methods to tempt the unreactive tropone to react in cycloadditions. First, we study the uncatalyzed and Lewis Acid (LA)-catalyzed cycloaddition reactions between tropone and 1,1-dimethoxyethene. Our findings reveal that LA catalysts, namely BF_3, $B(C_6H_5)_3$, and $B(C_6F_5)_3$, significantly enhance reaction rates and lower reaction barriers by up to 12 kcal mol^{-1} through LUMO-lowering catalysis.[1] Second, we explore how reversing the polarity of the carbonyl group (umpolung), e.g., by converting tropone into its hydrazone analogue, catalyzes the Diels-Alder reaction with maleimide. We challenge the established explanation attributed to antiaromaticity-induced HOMO raising.[2] Instead, we propose that the increased reactivity arises from enhanced asynchronicity, resulting in reduced strain and diminished destabilizing Pauli repulsion.[3] Our findings provide a deep understanding of the mechanism behind tropone activation.
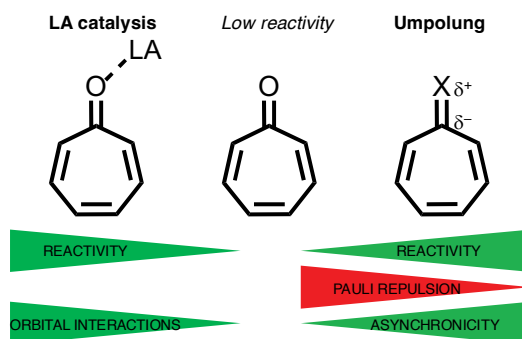
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SchNet4AIM: Towards Explainable Chemical AI (XCAI)

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The widespread of Artificial Intelligence (AI) has resulted in the proliferation of black boxes, extremely accurate but of elusive interpretation. While valuable, these tools hinder our understanding of chemical phenomena. To bridge this gap, we show how Explainable Chemical AI (XCAI) can emerge from integrating physically rigorous theories, such as the Atoms in Molecules framework,[1] with cutting-edge AI kernels. Encompassing a modified version of the SchNet architecture,[2] our approach (SchNet4AIM) can estimate local (atomic and pairwise) quantities with remarkable accuracy while ensuring the precise reconstruction of the corresponding molecular properties. Additionally, intrinsic explainability is showcased through the study of a supramolecular binding phenomenon, where SchNet4AIM provides quantum chemically consistent insights into the driving forces behind complexation and discerns the most dominant contributions to the latter. Overall, this approach goes beyond numerical precision by offering chemically interpretable insights, broadening the range of applicability of computationally demanding theoretical tools to previously unexplored domains.
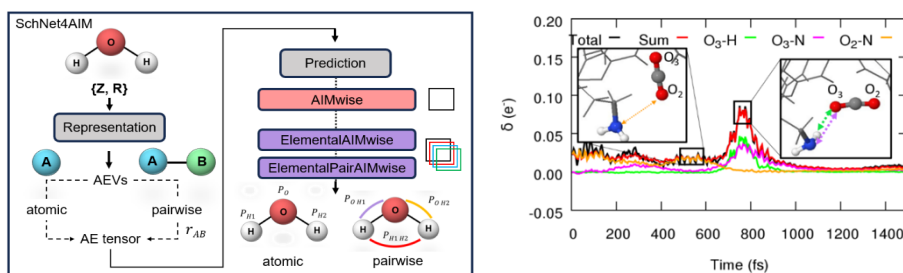
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Superexchange Interaction: from First-Principles to Canonical Models

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In magnetic insulators, the exchange interaction between two magnetic ions is not direct but mediated by a non-magnetic ion, known as the superexchange interaction. In cubic perovskites containing transition metal ions, this interaction leads to antiferromagnetic (AFM) ground states. However, the energy difference between the ferromagnetic (FM) and AFM states is only a few meV. The concept of superexchange was introduced by Kramers[1] in 1934 and further developed by Anderson[2], Goodenough-Kanamori[3,4] and Hay, Thibealt and Hoffmann[5] using dimer models. However, these models can provide at most semi-quantitative information and rough chemical insights into magnetism. In our work, we have employed first principles calculations together with both orbital-based (LOBSTER)[6] and density-based (QTAIM[7], TOPOND[8]) tools to unravel the chemical origin of superexchange interaction. A underlying symmetry-breaking principle and slightly larger covalency in the AFM state are the driving forces for the stabilization of the AFM phase below the FM phase. The results for model systems $KNiF_3$, KVF_3 and $KMnF_3$ shows that the key element in the stabilization of the AFM state is a more diffuse electron density associated with the spin-minority electrons, as confirmed by all chemical indicators such as COHP, COBI or kinetic energy at bond critical point.

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Post-translational Modification: Covalent Modification of Amino Acids in Cytochrome P460 Cofactor Maturation

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Post-translational modification (PTMs) in c-type cytochrome P460 through covalent cross-linking involves the heme porphyrin ring itself at *meso*-carbon with Lys amino acid of the protein.[1] The site-directed mutagenesis of Lys with Tyr or Leu does not cross-link and leads to catalytic inactivity for NH_2OH oxidation.[2,3] The origin of heme-Lys cross-link with leans of the functional and co-factor electronic structure remains elusive to date, and its study is highly demanding for mapping the artificial enzyme design. Specifically, the role of cross-link needs a virtuous theoretical prediction that has triggered the exciting advances in enzyme chemistry, particularly mechanistic insight.
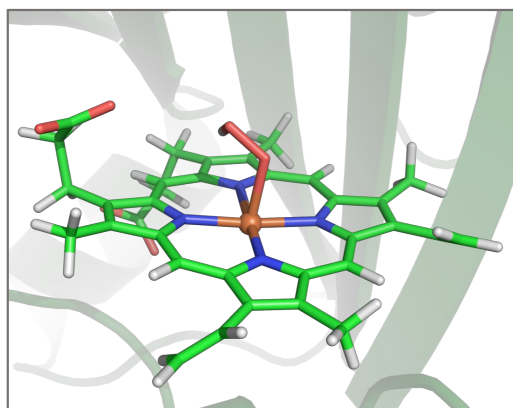

Figure 1: Active site for cyt P460 intermediate from *Nitrosomonas europea.* PDB ID: 8GAR

To this extent, we have studied the dynamics and mechanism for maturation of cross-linked cyt P460 as well as spectroscopic validation of intermediate observed by experimental studies using QM/MM calculation.

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