7th European Colloquium on Inorganic Reaction Mechanism

University of Debrecen

6th–9 th September 2026

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Welcome

Dear Colleagues,

It is our great pleasure to welcome you to the **7th European Colloquium on Inorganic Reaction Mechanisms (ECIRM 2026)**, which will be held in **Debrecen, Hungary, from September 6 to 9, 2026**.

Founded in Debrecen in 2013, the ECIRM conference series has been organized biennially across Europe, providing a vibrant platform for researchers to share their insights into inorganic reaction mechanisms and related areas of chemistry.

ECIRM 2026 will continue this tradition by bringing together scientists from around the world to discuss the latest developments in inorganic chemistry — including organometallic chemistry, equilibrium and structural dynamics, catalysis, and redox processes both in homogeneous and heterogeneous phases, as well as the analytical tools and techniques used to study them. Special attention will be devoted to nonconventional methods that reveal new mechanistic insights into reactive systems.

As always, ECIRM aims to offer a stimulating and collegial environment for scientific exchange, fostering collaboration and innovation across disciplines. The program will feature plenary and invited lectures, complemented by oral and poster presentations, covering all aspects of reaction mechanisms.

We warmly invite you to take full advantage of the rich scientific program and the informal opportunities for discussion and networking that make ECIRM such a unique and inspiring event.

We look forward to your contributions, and to welcoming you to Debrecen in September 2026.

On behalf of the Organizing Committee,

István Fábián, Conference Chairman

Committee

Chairman

István Fábián

Organizing Committee

Zsolt Baranyai

Attila Forgács

Petra Herman

Ferenc Joó

Norbert Lihi

Fruzsina Simon

Mária Szabó

Gyula Tircsó

Dóra Vargáné Szalóki

Scientific Program

6th of September (Sunday)		7th of September (Monday)	
		9:00 - 9:55	PL2 Alicia Casitas
		9:55 - 10:35	KN1 Michael L. Neidig
		10:35 - 10:55	O1 Maria Oszajca
		10:55 - 11:15	O2 Michael J. Zdilla
		11:15 - 11:45	Coffe break
		11:45 - 12:05	O3 Lukasz Orzel
		12:05 -12:25	O4 József Kalmár
		12:25 -12:45	O5 Rinaldo Poli
		12:45 -13:05	O6 Ádám Horváth
		13:05 - 14:30	Lunch
15:00 - 17:15	Registration	14:30 - 15:10	KN2 Tomasz Borowski
		15:10 - 15:50	IL János Elek
17:15 - 17:30	Opening Ceremony	16:00 -19:00	Poster session
17:30 -18:25	PL1 Sabine Van Doorslaer		
18:30 - 20:30	Welcome reception		

8th of September (Tuesday)		9th of September (Wednesday)	
9:00 - 9:55	PL3 Miquel Costas	10:00 - 11:40	KN5 Frédéric Banse
9:55 - 10:35	KN3 Éva Jakab Tóth	10:40 - 11:00	O15 Erik Kertész
10:35 - 10:55	O7 Daniela Lalli	11:00 - 11:20	O16 István Kapus
10:55 - 11:15	O8 Nicol Guidolin	11:20 - 11:40	O17 Ot Raich Panisello
11:15 - 11:45	Coffe break	11:40 -12:00	Closing Ceremony
11:45 - 12:05	O9 Zoltán Garda	12:00 -	Lunch
12:05 -12:25	O10 Marco Ricci		
12:25 -12:45	O11 Annette Rompel		
12:45 -13:05	O12 Csilla Fekete		
13:05 - 14:30	Lunch		
14:30 - 15:10	KN4 Christian Limberg		
15:10 - 15:30	O13 Luca Antonini		
15:30 - 15:50	O14 Jos Briggs-Pritchard		
18:00 - 21:00	Banquett		

Program

6th September 2026
Sunday

15:00 - 17:15 **Registration**

17:15 - 17:30 **Opening Ceremony**

17:30 - 18:25 **PL1 Sabine Van Doorslaer** – *Department of Chemistry*
Multifrequency pulsed electron paramagnetic resonance – a versatile spectroscopic tool for (bio)inorganic chemistry

18:30 - 20:30 **Welcome reception**

7th September 2026
Monday

09:00 - 09:55 **PL2 Alicia Casitas** – *Philipps-Universität Marburg*
Exploring the chemical landscape of high-valent organoiron complexes

09:55 - 10:35 **KN1 Michael L. Neidig** – *University of Oxford*
Down the Rabbit Hole of Iron Catalysis for Organic Synthesis

10:35 - 10:55 **O1 Maria Oszajca** – *Jagiellonian University*
Mechanisms of Ferric Heme-Mediated S-Nitrosothiols formation: The Role of the Iron Coordination Environment

10:55 - 11:15 **O2 Michael J. Zdilla** – *Temple University*
Molecular Mechanistic Considerations for Ion Hopping in Solid State Soft-Solid Molecular Crystal Electrolytes

11:15 - 11:45 **Coffe break**

11:45 - 12:05 **O3 Lukasz Orzel** – *Jagiellonian University*
Interplay between homocysteine, nitric oxide and cobalt porphyrinoids in cobalamin-related processes

12:05 - 12:25 **O4 József Kalmár** – *University of Debrecen*
Mechanistic explanation for differences between catalytic activities of dissolved and aerogel immobilized macrocyclic Cu(II) complexes

12:25 - 12:45 **O5 Rinaldo Poli** – *Université de Toulouse*
Mechanistic investigations of the metal-catalyzed acrylate radical termination

12:45 - 13:05 **O6 Ádám Horváth** – *Budapest University of Technology and Economics*
Nucleophilic Substitution at Elemental Iodine: Uncovering the Reaction Mechanism

13:05 - 14:30 **Lunch**

14:30 - 15:10 **KN2 Tomasz Borowski** – *Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences*
Reaction mechanisms of selected mononuclear non-heme iron enzymes – experiments and simulations

15:10 - 15:50 **IL János Elek** – *Science Port Ltd.*
Spectroscopic investigation of species-number estimation and equilibrium oligomerization: PCR-based indirect rank estimation from a UV spectral series of methylene blue solutions

16:10 - 19:00 **Poster session**

8th September 2026
Tuesday

09:00 - 09:55 **PL3 Miquel Costas** – *Universitat de Girona*
Mechanistic versatility of biologically inspired catalysts in aliphatic C-H oxidation reactions

09:55 - 10:35 **KN3 Éva Jakab Tóth** – *Centre of Molecular Biophysics, CNRS*
Manganese complexes for MRI applications

10:35 - 10:55 **O7 Daniela Lalli** – *University of Eastern Piedmont*
Multinuclear and multi-frequency NMR investigations of fluoride binding to metal complexes

10:55 - 11:15 **O8 Nicol Guidolin** – *Bracco Imaging SpA*
Digadoglucitol: A New High Relaxivity MRI Contrast Agent Based on the Dimerization of [Gd(HP-DO3A)] and Activated Intramolecular Catalysis of the Prototropic Exchange

11:15 - 11:45 **Coffe break**

11:45 - 12:05 **O9 Zoltán Garda** – *University of Debrecen*
Fluorine Containing Iron Complex as a Redox-Switchable ^{19}F MRI Probe

12:05 - 12:25 **O10 Marco Ricci** – *University of Eastern Piedmont*
Field-Dependent ^{1}H Relaxometry as a General Probe of Hydration Dynamics and Metal–Water Exchange in Paramagnetic Ln^{3+} Complexes

12:25 - 12:45 **O11 Annette Rompel** – *Universität Wien*
Polyoxometalate speciation in solution: from mechanistic atlases to antiviral and transport processes

12:45 - 13:05 **O12 Csilla Fekete** – *Budapest University of Technology and Economics*
Substitution reactions of the weak Lewis pair H_3P-$AlCl_3$: mechanistic insights

13:05 - 14:30 **Lunch**

14:30 - 15:10 **KN4 Christian Limberg** – *Humboldt-Universität zu Berlin*
Routes to Bioinspired Nickel-Carbonite Entities and its Reactivity towards Oxalate

15:10 - 15:30 **O13 Luca Antonini** – *Université de Toulouse*
Dinitrogen activation and functionalization mediated by metal complexes

15:30 - 15:50 **O14 Jos Briggs-Pritchard** – *University of Oxford, Oxford*
Lifting The Lid on Iron-Catalysed Reductive Alkyl-Alkyl Cross-Couplings

18:00 - 21:00 **Banquett**

9th September 2026
Wednesday

10:00 - 10:40 **KN5 Frédéric Banse** – *Université Paris-Saclay*
Non heme iron complexes for the activation of small molecules

10:40 - 11:00 **O15 Erik Kertész** – *Budapest University of Technology and Economics*
Catalytic application of P,C,P-Ge and Sn chelate complexes in CO_2 activation

11:00 - 11:20 **O16 István Kapus** – *University of Debrecen*
Rigid 8-Hydroxyquinoline-Functionalized Macrocyclic Chelators for Mn(II): Thermodynamic, Relaxometric, and Kinetic Studies

11:20 - 11:40 **O17 Ot Raich Panisello** – *Universitat de Barcelona*
Metal Coordination as a Tool for Controlling Azo Thermal Isomerization Pathways

11:40 -12:00 **Closing Ceremony**

12:00 - **Lunch**

Poster presentations

P1 Alexis Cabahug Achacoso
Thermodynamic and Kinetic Evaluation of NOTA-NP, a possible Mn(II)-based liver-specific probe

P2 Dóra Bonczidai-Kelemen
SOD and catalase-like activities of a NiSOD related metallopeptide

P3 Balázs Bukta
Resorcinol–formaldehyde–gelatin aerogel for the selective removal of aqueous Au(III) ions

P4 Szilvia Bunda
The chemical characterization of paramagnetic metal complexes containing malonate pendants

P5 Csilla Enikő Czégéni
Catalytic properties of symmetric and asymmetric Rh(I)-N-heterocyclic carbene complexes in nitrile hydration

P6 Alexandra Czuna
Experimental design and optimization: Hydrogen storage in ammonia borane via aqueous media

P7 Dániel Pércsi

Development of aerogel-based sorbents for the selective recovery of noble metal ions and investigation of their binding mechanisms

P8 Róbert Diószegi

Copper(II) complexes of pyridine-based macrocycles with antioxidant activity

P9 Montserrat Ferrer

Coordination of azoderivatives to the $\{Pt^{II}(TMEDA)\}^{2+}$ fragment; robustness of the E↔Z photothermal py-Ph ligand isomerisation and striking influence of the solvent in the Z→E thermal process

P10 Attila Forgács

Interaction of Aqueous Bovine Serum Albumin with Silica Aerogel Microparticles: Sorption Induced Aggregation

P11 Zoltán Horváth

Effect of fluoride ions on homogeneous catalytic CO_2 hydrogenation

P12 Dávid Anygal

The formation of chloroacetic acid during the chlorination of aspartic acid

P13 Ferenc K. Kálmán

An old-new ligand family for complexation of Cu(II) in radiotheranostics

P15 Eszter Kiss

Vitamin loaded PVA electrospun nanofibers

P16 Manuel Martínez

Attachment of py-Ph azoderivatives to the $\{Ru^{II}cis\text{-}(bpy)_2\}^{2+}$ skeleton; coexistence of the photothermal cis↔trans skeleton and E↔Z ligand isomerisation reversible reactions

P17 Dávid Molnár

Homogeneous Hydrogenation of CO_2/HCO_3^- in Aqueous Media Using the *cis,mer*-$[IrH_2Cl(mtppms\text{-}Na)_3]$ Catalyst

P18 Fruzsina Simon

Catechol oxidase activity of a dinuclear copper(II) complex

P19 Balázs Szilágyi

Structure–Property Relationships in Acyclic Lanthanide Chelators

P20 Antal Udvardy

Water-Soluble Ru(II)–PTA Catalysts for Reversible Hydrogen Storage Applications

P21 Dóra Vargáné Szalóki

Copper(II) complexes of histidine-based benzo-fused heterocyclic ligands: equilibrium and kinetic features

P22 Natalia Walas

The Reactivity of Cobalt Porphyrinoids toward NO

Plenary Lectures

Multifrequency pulsed electron paramagnetic resonance – a versatile spectroscopic tool for (bio)inorganic chemistry

Sabine Van Doorslaer[a]

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Paramagnetic (open-shell) systems very often play a crucial role in (bio)chemical processes. When present, these paramagnetic states will critically influence the reaction pathways or lie at the basis of the specific properties of the molecules and materials. Electron paramagnetic resonance (EPR) provides a unique spectroscopic tool to study paramagnetic systems. The EPR toolbox contains numerous methods, including multifrequency continuous-wave (CW) EPR techniques and different pulsed EPR sequences, that target different parameters. Combination of these methods with rapid freeze-quench methods, electrochemistry or optical excitation even broadens the applicability of these methods.

Using examples from my own collaborative research on the elucidation of biochemical pathways in metallo proteins, the study of reaction mechanisms in homogeneous and heterogeneous catalysis and the development of hybrid materials for biosensing, the power of modern-day EPR will be highlighted. While many of the research questions strongly differ, the common factor is the presence of (intermediate) paramagnetic systems that are challenging to characterize with other characterization techniques.

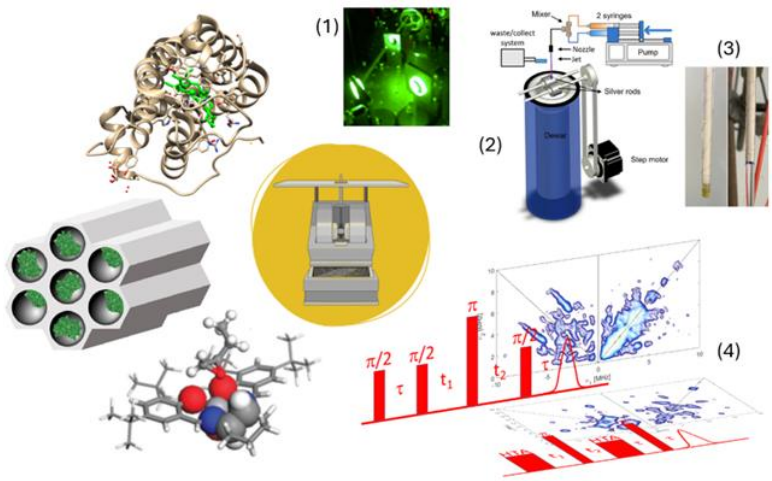

Figure 1. Cartoon depicting the combination of the standard continuous-wave EPR technique (central) with optical excitation (1), a rapid freeze-quench set-up (2), electrochemistry (3) and pulsed EPR techniques (hyperfine spectroscopy, 4) to address a variety of paramagnetic systems (left).

Exploring the chemical landscape of high-valent organoiron complexes

Alicia Casitas*

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Organometallic iron complexes in formally high oxidation state that contain either metal–carbon σ-bonds or metal–carbon multiple bonds (alkylidenes and carbynes) are exceedingly rare, largely due to their inherent thermal instability. To address this gap, we initiated a research program focused on the synthesis, structural and spectroscopic characterization, and reactivity studies of novel high-valent organometallic iron complexes. Our studies focused on metal complexes with distinctive electronic and/or coordination environments, as such systems have the potential to unlock new chemical transformations.

To access organoiron(IV) complexes, we are investigating iron-promoted oxidative group transfer reactions with several λ^3-iodanes. Indeed, iodine(III) reagents are widely used in organic synthesis as powerful oxidants and versatile group-transfer reagents. However, their activation with iron remains underexplored, despite its potential for the development environmentally friendly bond-forming catalytic methodologies.

First, I will present synthetic strategies to prepare Fe(III) and Fe(IV) cyanide complexes using cyano λ^3-iodanes.[1] Then, I will discuss the synthesis of highly reactive organometallic alkynylferrates(III) and Fe(IV) alkynylide complexes, as well as their role in carbon-carbon bond-forming reactions.[2] Special emphasis will be given to the synthesis and electrochemical properties of the studied λ^3-iodanes.[3] Finally, mechanistic studies in alkynyl oxidative transfer reactions promoted by iron complexes to form Fe(IV) alkynylide complexes will be disclosed. Gaining fundamental insights into the reactivity of organoiron species in high oxidation state may ultimately find applications in catalysis towards organic synthesis, particularly in oxidative group-transfer reactions.[4]

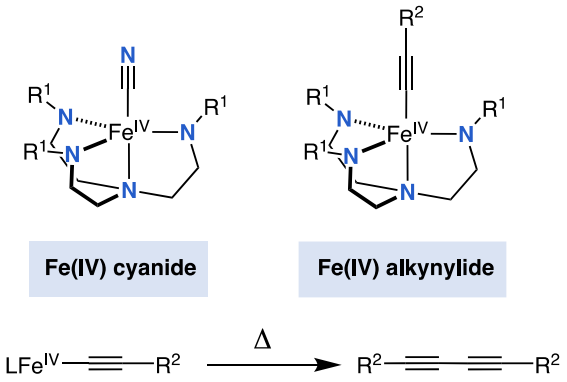

Figure 1. Synthesis of high-valent iron complexes and study of their reactivity.

References

[1] Souilah, C.; Jannuzzi, S. A. V.; Demirbas, D.; Ivlev, S.; Swart, M.; DeBeer, S.; Casitas, A.* *Angew. Chem. Int. Ed.* **2022**, *61*, e202201699.

[2] Souilah, C.[#]; Jannuzzi, S. A. V.[#]; Demirbas, D.; Ivlev S., Xie, X; Peredkov, S; DeBeer, S.*, Casitas, A.* *Angew. Chem. Int. Ed.* **2025**, *64,* e202421222.

[3] Debbeler, F.;# Jenisch, D.;# Souilah, C.; Moths, P.; Ivlev, S.; Casitas, A.* *Synthesis* **2025**, *57,* 2946-2962. DOI: 10.1055/a-2650-7789.

[4] Casitas, A.*; Andreetta, P. Chapter 2 - Iron-catalyzed group-transfer reactions with iodine(III) reagents in Advances in Catalysis, Vol. 74 (Eds.: T. Ollevier, M. Diéguez), Academic Press, **2024**, pp. 33-99.

Mechanistic versatility of biologically inspired catalysts in aliphatic C-H oxidation reactions

Miquel Costas[a]

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C(sp^3)–H bond oxygenation is an important class of C–H functionalization reactions with enormous synthetic potential.[1] The reaction is performed by numerous iron-dependent enzymes that operate via high valent iron-oxo species. These enzymatic reactions have served as inspiration motifs for the development of C–H oxidation catalysts.[2] Investigated for long, the current mechanistic consensus is that heme and non-heme monoiron-dependent oxygenases hydroxylate C–H bonds by a similar rebound mechanism.[3,4] The reaction is initiated by a hydrogen atom transfer (HAT) from a substrate C–H bond to generate a carbon radical that is then trapped by hydroxyl ligand transfer to form the hydroxylated product. In monoiron-dependent non-heme enzymes, the structural versatility of the metal coordination sphere enables alternative reactivity patterns.[5]

Iron and manganese complexes containing tetradentate aminopyridine ligands are powerful C–H oxidation catalysts that are able to promote selective aliphatic C–H bond hydroxylation. Mechanistic studies point toward a common mechanistic scenario for iron and manganese catalysts where C–H hydroxylation proceeds via an enzymatic-like HAT/rebound mechanism executed by high-valent metal-oxo species.[6] Alternative reactions entailing the transfer of the ligand cis to oxo[7] and desaturation[8] have been observed only in selected cases where, however, these pathways are always accompanied by the canonical hydroxylation reaction, which typically dominates the reactivity. A general understanding of the factors that govern these divergent reactivities is lacking. In this lecture we will discuss our efforts on designing this class of catalysts for addressing aliphatic C-H oxidation reactions and the mechanistic portfolio that emerges from these studies, pointing to alternative scenarios to the classical rebound mechanism.[9]

Acknowledgment Economic support from European Research Council, (883922), Spain Ministry of Science, (MINECO, TED2021-132648B-I00, PID2024-162777NB-I00). Generalitat de Catalunya, (ICREA Academia).

References

1 White, M. C.; Zhao, J. *J. Am. Chem. Soc.* **2018**, *140*, 13988– 14009
2 Vicens, L.; Olivo, G.; Costas, M. *ACS Catal.* **2020**, *10*, 8611– 8631
3 Huang, X.; Groves, J. T. *Chem. Rev.* **2018**, *118*, 2491– 2553
4 Kal, S.; Que, L. *J. Biol. Inorg. Chem.* **2017**, *22*, 339– 365
5 Krebs, K.; Galonić Fujimori, D.; Walsh, C- T.; Bollinger, Jr., M. *Acc. Chem. Res.* **2007**, *40, 7*, 484–492
6 Ottenbacher, R. V.; Talsi, E. P.; Bryliakov, K. P. *ACS Catal.* **2015**, *5*, 39– 44
7 a) Ottenbacher, R. V.; Bryliakova, A. A.; Shashkov, M. V.; Talsi, E. P.; Bryliakov, K. P. *ACS Catal.* **2021**, *11*, 5517–5524, b) Company, A.; Gómez, L.; Güell, M.; Ribas, X.; Luis, J. M.; Que, L., Jr; Costas, M. *J. Am. Chem. Soc.* **2007**, *129*, 15766– 15767, c) Cianfanelli, M.; Olivo, G.; Milan, M.; Klein Gebbink, R. J. M.; Ribas, X.; Bietti, M.; Costas, M. *J. Am. Chem. Soc.* **2020**, *142*, 1584– 1593.
8 Bigi, M. A.; Reed, S. A.; White, M. C. *Nat. Chem.* **2011**, *3*, 216– 222.
9 a) Galeotti, M.; Vicens, L.; Salamone, M.; Costas, M.; Bietti, M. *J. Am. Chem. Soc.* **2022**, *144*, 7391– 7401. b) Call, A.; Cianfanelli, M.; Besalú-Sala, P.; Olivo, G.; Palone, A.; Vicens, L.; Ribas, X.; Luis, J. M.; Bietti, M.; Costas, M. *J. Am. Chem. Soc.* **2022**, *144*, 19542– 19558. c) Galeotti, M. ; Bietti, M. ; Costas, M. *J. Am. Chem. Soc.* **2024**, *146, 13*, 8904–8914. d) Palone, A. ; Call, A. ; Garcia-Roca, A. ; Luis, J. M. ; Sigman, M. S. ; Bietti, M. ; Nevado, C. ; Costas. M. *Angew. Chem. Int. Ed.* **2025**, *64* (30), e202507755.

Breaching the nitrido wall using novel reaction mechanisms

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The oxo (nitrido) wall delineated by Harry Gray explains the rarity of oxo (and nitrido) complexes of transition metals in group 9 and beyond by noting the incompatibility of the low *d* electron counts needed for productive π bonding in common tetragonal coordination geometries and the inaccessibility of the resulting oxidation states for late metals. I will describe a breach in this wall, namely the preparation of square pyramidal terminal iridium(VII) nitride complexes. The key step in their preparation, N atom transfer from a coordinated azide, is enabled by the use of redox-active iminoxolene ligands, which are actually *reduced* as the oxidation reaction proceeds. This allows readily available iridium(III) bis(iminosemiquinone) precursors to be transformed into the iridium(VII) bis(amidophenoxide) products, whose d^2 configuration permits strong metal-nitrogen π bonding. The relevance of this "4 – 2" electron redox process to the reactivity of the high-valent iridium nitrides will be discussed.

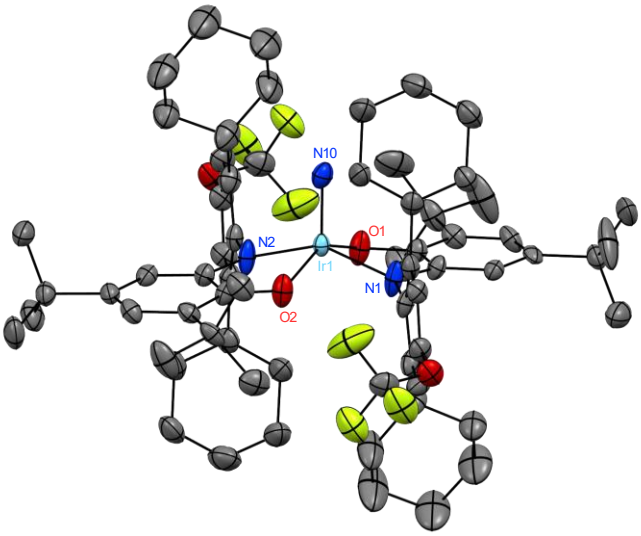

Figure 1. Structure of square pyramidal nitrido-bis(amidophenoxide)iridium(VII)

Keynote Lectures

Down the Rabbit Hole of Iron Catalysis for Organic Synthesis

Michael L. Neidig

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The development of iron-based methods for organic synthesis continues to attract broad research interest, offering both improved sustainability and the potential for novel reactivities in comparison to traditional palladium systems. However, the nature of the iron intermediates and reaction pathways central to effective catalysis remain poorly defined. In order to push iron to its ultimate synthetic potential via mechanism-driven methods development, it is essential that we develop molecular-level insight into the iron species involved in bond making (C-C, C-B, etc.) and bond breaking (C-H, C-C) reactions central to modern organic synthesis. Towards this goal, mechanistic studies from our group over the past decade have defined key iron intermediates and reaction pathways central to effective catalysis, including the central role of organoferrates in numerous reactions.[1-4] This presentation will highlight recent studies in our group across cross-coupling and C-H activation.

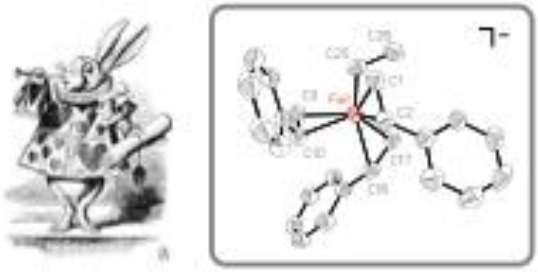

Figure 1. A representative organoiron ferrate central to organic synthesis

References

[1] Neidig, M. L.; Carpenter, S. H.; Curran, D. J.; DeMuth, J. C.; Fleischauer, V. E.; Iannuzzi, T. E.; Neate, P. G. N.; Sears, J. D.; Wolford, N. J. *Acc. Chem. Res.* **2019**, *52*, 140-150.

[2] Gimeno, M.; Aguilera, M. C..; Fleischauer, V. E.; Brennessel, W. W.; Neidig, M. L. *Angew. Chem. Int. Ed.* **2025**, e202413566.

[3] Radovic, A.; Healy, M. C.; Cai, L.; Diaz, S.; Datta, A.; Das, D.; Gogoi, A. R.; Wolford, A. J.; Carpenter, S. H.; Brennessel, W. W.; McCamant, D. W.; Gutierrez, O.*; Neidig, M. L. *Chem. Sci.* **2026**, 17, 7002-7009.

[4] Panda, J.; Gimeno, M.; Gogoi, A.; Chen, Z.; Garhwal, S.; Levy, L.; Kaushanksky, A.; Fridman, N.; Briggs-Pritchard, J.; Gershoni-Poranne, R.; Neidig, M. L.; de Ruiter, G. *Angew. Chem. Int. Ed.* **2026**, *65*, e3094782.

Reaction mechanisms of selected mononuclear non-heme iron enzymes – experiments and simulations

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b) Czech Academy of Sciences, J. Heyrovský Institute of Physical Chemistry: Prague, Czech Republic
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Mononuclear non-heme iron (NHI) enzymes catalyze a wide range of reactions, many of which are involved in the biosynthesis of specialized secondary metabolites. Recently, we have been studying three such NHI enzymes from plants: two alpha-ketoglutarate (AKG) - dependent dioxygenases involved in the biosynthesis of alkaloids, and one extradiol dioxygenase involved in the biosynthesis of betalamic acid – a chromophore of betalain pigments. For codeine O-demethylase (CODM) from *Opium poppy*, we have obtained a crystal structure in complex with protopine – an alkaloid that is the preferred substrate of CODM, which has revealed details of enzyme-substrate interactions. Molecular dynamics simulations and subsequent QM/MM investigations into the mechanism of demethylenation reaction complemented the crystallography results [1]. Hyoscyamine 6-beta-hydroxylase (H6H) from *Datura metel* is an AKG-dependent enzyme that catalyzes the last two steps in the biosynthesis of scopolamine: hydroxylation of hyoscyamine to yield anisodamine, and oxidative cyclization of anisodamine to scopolamine. We have obtained crystal structures relevant to both reactions of H6H, used Mössbauer spectroscopy to probe the coordination environment of the active-site iron, and used molecular dynamics simulations and QM/MM calculations to investigate the reaction mechanism. The obtained results allowed us to propose the mechanism employed by H6H to avoid the thermodynamically preferred hydroxylation reaction in favor of closing the epoxide ring of scopoloamine [2,3]. L-DOPA dioxygenase (DODA) from *Beta vulgaris* catalyzes oxidative cleavage of the catechol ring of L-DOPA, yielding 4,5-seco-DOPA, which spontaneously cyclizes to betalamic acid. We have recently structurally characterized several complexes formed by DODA with catechol or catechol-like substrates, used Mössbauer spectroscopy to probe the state of the Fe(II) ion in the enzyme-substrate complex, and investigated the key steps of the catalytic reaction with DFT modeling. The results obtained helped explain the regioselectivity of ring cleavage by BvDODA [4].

Acknowledgment
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References

[1] Miłaczewska-Kręgiel, A.; Kurpiewska, K.; Borowski, T., in preparation.

[2] Kluza, A.; Wojdyla, Z.; Mrugala, B.; Kurpiewska, K.; Porebski, P.J.; Niedzialkowska, E.; Minor, W.; Weiss, M.S.; Borowski, T., *Dalton Trans.* **2020**, *49* (14), 4454-4469.

[3] Kluza, A.; Wojdyla, Z.; Korecki, J.; Chruszcz, M.; Sarewicz, M.; Bujnowicz, Ł.; Osyczka, A.; Bugno, R.; Borowski, T., in preparation.

[4] Kluza, A.; Seweryn-Ożóg, K.; Hapke, M.; Andrys-Olek, J.; Kachhap, S.; Miłaczewska-Kręgiel, A.; Tataruch, M.; Jahan, F.; Freindl, K.; Korecki, J.; Sarewicz, M.; Osyczka, A.; Borowski, T., submitted.

Manganese complexex for MRI applications

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Following toxicity and ecological concerns related to the use of Gd in MRI, there is active research for safer alternatives. Mn^{2+} chelates have great promise; however, it is difficult to achieve high complex stability and kinetic inertness for the highly labile Mn^{2+}, while retaining good relaxation features. We have demonstrated that rigid, pre-organized bispidine ligands provide exceptional properties in this respect.[1]

We also explore the potential of fluorine-containing Mn^{2+} and Mn^{3+} chelates as alternatives to perfluorinated nanoparticles in ^{19}F MRI. When several equivalent ^{19}F atoms are placed at an appropriate distance from the metal, these paramagnetic ions generate maximized relaxation effect which can be harvested by using ultrafast acquisition sequences. The redox properties of manganese can be further exploited to design redox responsive ^{19}F MRI agents.[2]

References

[1] (a) Ndiaye, D. ; Sy, M. ; Pallier, A. ; Même, S. ; de Silva, I.; Lacerda, S. ; Nonat, A.M. ; Charbonnière, L. J. and Tóth, É. *Angew. Chem. Int. Ed.* **2020**, *59*, 11958. (b) Cieslik, P.; Comba, P.; Dittmar, B.; Ndiaye, D.; Tóth, É.; Velmurugan, G.; Wadepohl, H. *Angew. Chem. Int. Ed.* **2022**, *61*, e202115580, (c) Ndiaye, D.; Cieslik, P.; Wadepohl, H.; Pallier, A.; Même, S.; Comba, P.; Tóth É. *J. Am. Chem. Soc.* **2022**, *144*, 22212. (d) Ndiaye, D.; Sy, M.; Thor, W.; Charbonnière, L. J.; Nonat A. M. and Tóth, É. *Chem. Eur. J.* **2023**, *29*, e202301880; (e) Sy, M.; Ndiaye, D.; Meudal, H.; Charbonnière, L. J.; Nonat A. M. and Tóth, É., *Chemistry Europe* **2025**, e202500263. (f) Mahamoud, A.; Garda, Z.; Bouvet, J.; Ndiaye, D.; Policar, C.; Elhabiri, M.; Tóth, É.; and Nonat A. M., *Inorg. Chem.* **2026**, doi.org/10.1021/acs.inorgchem.6c01966.

[2] (a) Garda, Z.; Szeremeta, F.; Quin, O. ; Molnár, E. ; Váradi, B. ; Clémençon, R. ; Même, S. ; Pichon, C. ; Tircsó, G.; Toth, E. *Angew. Chem. Int. Ed.* **2024**, *63*, e202410998. (b) Garda, Z.; Szeremeta, F.; Tóth, C. N.; Bunda, S.; Pifferi, C.; Clémençon, R.; Même, S.; Tircsó, G. and Tóth É. *J. Am. Chem. Soc.* **2025**, *147*, 18017–18024. (c) Garda, Z.; Pallier, A.; Nagy, T.; Szeremeta, F.; and Tóth, É. *Chem. Eur. J.* **2025**, 202502751. (d) Pinto, S. M.A.; Ferreira, A. R.R.; Teixeira, D. S.S.; Nunes, S. C.C.; Batista de Carvalho, A. L.M.; Almeida, J. M. S.; Garda, Z.; Pallier, A;. Pais, A. A.C.C.; Brett, C. M.A.; Tóth, É.; Marques, M. P.M.; Pereira M. M. and Geraldes C. F.G.C. *Chem. Eur. J.* **2023**, *29*, e202301442.

Routes to Bioinspired Nickel-Carbonite Entities and its Reactivity towards Oxalate

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We report on the generation of Ni–CO_2^{2-}···M complexes (M = alkali,[1-3] earth alkaline[4] or transition metal ion[6]) via hitherto rarely observed formate β-deprotonation.[1-3] The CO_2^{2-} (carbonite) ligand is bound like a carbene to the nickel centre and was found to interact with the counterions M^+, introduced via the used bases or salt metathesis reactions. Through their properties they thus significantly influence the stability and reactivity of the complexes, which resemble the CO_2 bound state in Ni,Fe carbon monoxide dehydrogenases (CODH),[5] in particular the Ni–CO_2^{2-}···Fe representative.[6] For the series of systems presented an inverse relation between redox behaviour and activation emerged: transition metal ions reduce the reduction potential of the carbonite unit but increase its tendency to undergo C-O bond cleavage.[6] For certain counter ions a reaction route becomes accessible, which opens up C-C coupling reactions leading to oxalate and mesoxalate,[2] and the mechanism will be discussed.[7]

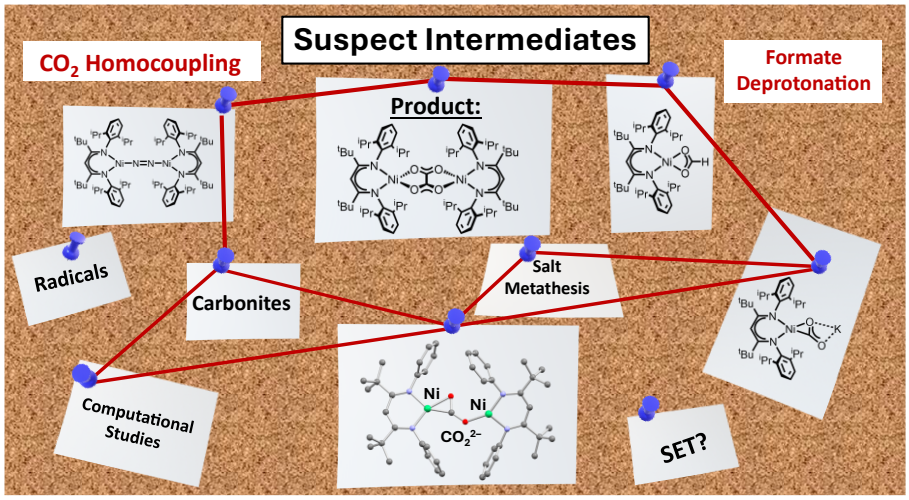

Figure 1. Involvement of Nickel Carbonites in the Formation of Oxalate

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References

[1] P. Zimmermann, S. Hoof, B. Braun-Cula, C. Herwig, C. Limberg, *Angew. Chem. Int. Ed.* **2018**, *57*, 7230-7233.

[2] P. Zimmermann, D. Ar, M. Rößler, P. Holze, B. Braun, C. Herwig, C. Limberg, *Angew. Chem. Int. Ed.* **2021**, *60*, 2312-2321.

[3] S. Wolff, V. Pelmenschikov, R. Müller, M. Ertegi, B. Cula, M. Kaupp, C. Limberg, *Chem. Eur. J.* **2024**, 30, e202303112.

[4] S. Wolff, A. Ponsonby, A. Dallmann, C. Herwig, F. Beckmann, B. Cula, C. Limberg, *Chem. Commun.* **2024**, *60*, 5816-5819

[5] J. Fesseler, J.-H. Jeoung, H. Dobbek, *Angew. Chem. Int. Ed.* **2015**, *54*, 8560

[6] S. Wolff, A. M. Hofmann, K. B. Krause, K. Weisser, T. Lohmiller, C. Herwig, C. Limberg, *Angew. Chem. Int. Ed.* **2025,** *64,* e202419675.

[7] S. Wolff, S. Wittek, A. Hofmann, M. Ertegi, K. Krause, M. Römelt, C. Limberg, *ChemRxiv*. DOI: https://doi.org/10.26434/chemrxiv-2025-0qg03

Non heme iron complexes for the activation of small molecules

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Despite efforts to reduce the impact of human activities on the environment, polluting and energy-consuming chemical processes still need to be adapted. This is particularly true for oxidation reactions, which account for considerable tonnages in industry. Indeed, these reactions often require stoichiometric quantities of toxic or harmful oxidants.[1] In contrast, nature has developed iron-based metalloenzymes that catalyse the oxidation of organic substrates by oxygen and release only water as a by-product.[2] These enzymes activate O_2 using 2 electrons and 2 protons to form high-valent iron-oxo species (FeO) capable of oxidising a wide variety of organic molecules. During the enzymatic cycle, other than FeO, various oxidizing intermediates are formed such as Fe-superoxo ($FeOO^{\bullet}$), Fe-peroxo ($FeOO^{-}$), and Fe-hydroperoxo (FeOOH).[3] In Cytochromes P450, the generation of these reaction intermediates relies on the nature of the first and second coordination spheres of the metal center which tune its redox potential / electron density and electrostatic environment (**push-pull effect**, Figure 1 a).

Methane monooxygenase (MMO) is a non heme enzyme which performs the extremely difficult oxidation of methane to methanol within its dinuclear active site.[4] The two iron atoms participate successively in the activation of O_2 to generate (i) an Fe^{III}-superoxo intermediate after injection of the first electron by an Fe^{II} center, then (ii) an Fe^{III}-peroxo intermediate after the second reduction. The cleavage of the O-O bond transforms the latter into the μ-oxo Fe^{IV} intermediate, which ultimately oxidises methane (Figure 1 b).

The mechanisms briefly described here provide inspiration for the development of bioinspired synthetic oxidation catalysts. With this in mind, we have prepared Fe complexes to perform the activation of small molecules. Results related to these studies will be presented with focus on reaction mechanisms.

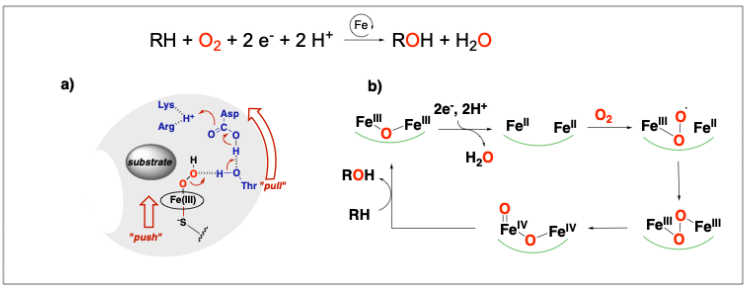

Figure 1. Overall reaction for the activation of O_2 and **(a)** representation of the O-O bond cleavage of the $Fe^{III}OOH$ intermediate in cyt. P450 illustrating the crucial roles played by the first and second coordination spheres in the active site (push-pull effect); **(b)** schematic representation of the catalytic cycle of MMO, illustrating the formation of oxidizing reaction intermediates by reductive activation of O2 and the oxidation of the alkane substrate (RH).

References

[1] Teles, J. H. *et al. Oxidation in Applied Homogeneous Catalysis with Organometallic Compounds: A Comprehensive Handbook in Four Volumes, Third Edition*. **64,** 465–568 (Wiley, 2017).

[2] Kal S., Que L., *J Biol Inorg Chem* **2017**, *250*, 625–27.

[3] Ray, K., Pfaff F. F., Wang B., Nam W. *et al.* . *J. Am. Chem. Soc.* **2014,** *136*,13942–13958.

[4] A. J. Jasniewski, L. Que, *Chem. Rev.* **2018**, *118*, 2554–2592.

Invited Lecture

Spectroscopic Investigation of Species-Number Estimation and Equilibrium Oligomerization: PCR-Based Indirect Rank Estimation from a UV Spectral Series of Methylene Blue Solutions

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Reliable reaction-kinetic calculations and mechanistic modelling ultimately depend on a fundamental question: how many chemically distinct species are present in the system under the conditions studied? However, when concentration-dependent UV-Vis spectra are nonlinear, the answer is not necessarily obvious. Deviations may arise from instrumental or Beer-Lambert limitations, but they may also reflect changing equilibria between several absorbing forms. Methylene blue (MB) was selected as a model system in which concentration-dependent oligomerization provides a well-characterized but spectroscopically challenging test case.

The factor analysis-based techniques for rank analysis are not completely unknown, but the articles focus on different aspects. In this work, a conventional chemometric method is used in an unconventional way to provide an unconventional solution to a conventional problem of reaction kinetics. Principal component regression (PCR), combined with cross-validation and residual diagnostics, is applied not primarily for concentration prediction, but as an indirect probe of the effective spectral rank of a UV-Vis data matrix. Measurements were designed to remain within the linear Beer-Lambert regime by using appropriate optical path lengths and subsequent path-length normalization, so that additional spectral dimensions could be interpreted chemically rather than as detector or optical-density artifacts. The optimal number of principal components was selected via cross-validation and further evaluated through residual analysis. Individual PCs are therefore treated as effective spectral directions that approximate matrix rank, not as species in a one-to-one sense.

Application of this approach to different concentration regions of aqueous MB shows that the dimensionality of the spectral data changes systematically as oligomerization becomes important. At low concentration, the spectra are essentially dominated by a single direction, whereas additional reproducible spectral dimensions emerge in regions where dimers and higher aggregates contribute. The results agree qualitatively with the established equilibrium distribution of MB and demonstrate that cross-validated PCR can distinguish chemically meaningful changes in spectral rank even when individual oligomers have strongly overlapping spectra. The method does not yield an absolute species count and cannot resolve every aggregate separately; rather, it provides a cautious experimental constraint on the minimum number of independent spectral contributions required by the data. In this sense, PCR coupled with cross-validation and residual diagnostics offers a complementary way to address one of the basic prerequisites of reaction-kinetic modeling: establishing how many distinguishable chemical components must be considered before a mechanistic model is constructed.

References

1 Kalmár, J.; Lente, G.; Fábián, I. *Dyes Pigm*. **2016**, *127*, 170-178.

Oral Communications

Mechanisms of Ferric Heme-Mediated S-Nitrosothiols formation: The Role of the Iron Coordination Environment

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Nitric oxide influences the biology of living cells through various mechanisms, one of which is S-nitrosation, recognized as a signalling modification.[1] The ferric heme–mediated conversion of nitric oxide and thiols into S-nitrosothiols constitutes an important reaction pathway in nitric oxide chemistry and is accompanied by the formation of NO-ferroheme, now recognized as mobile signaling entity in the vasculature.[2] However, the underlying molecular mechanisms remain controversial. In particular, it is unclear which elementary steps govern product formation and how the iron coordination environment controls the reaction outcome.
To address these questions, we performed a comparative mechanistic study of ferric heme–assisted S-nitrosation using two complementary model systems: N-acetylmicroperoxidase-11 (AcMP-11), featuring a single labile coordination site *trans* to a histidine ligand, and ferric TMPS porphyrin (meso-tetrakis(sulfonatomesityl)porphyrinato-iron(III)) with two labile axial coordination sites.[3,4] The efficient generation of biologically relevant RSNOs, including S-nitrosoglutathione and S-nitrosocysteine, was confirmed in quantitative spectrofluorimetric and electrochemical assays.
By combining time-resolved UV–vis and stopped-flow kinetics with Raman, EPR spectroscopy, and DFT calculations, we identified distinct coordination-dependent pathways leading to the same final products: S-nitrosothiols and NO-ferroheme. In histidine-ligated AcMP-11, S-nitrosothiols formation proceeds exclusively via nucleophilic attack of thiolate on the Fe^{2+}–NO^{+} moiety, yielding a transient N-coordinated RSNO–iron intermediate.[3] The alternative pathway involving formation of the thiolated AcMP 11 derivative represents a non-productive, dead-end equilibrium, owing to the lack of NO reactivity toward the coordinated thiol. In contrast, in the (TMPS)Fe^{3+} system, NO attack on the coordinated thiolate operates as a key step of the reaction pathway but must be preceded by NO coordination trans to the thiolate, resulting in the formation of a thiolate-ligated ferric heme–nitrosyl complex, (TMPS)Fe(NO)(RS).[4]
Moreover, we demonstrated that oxygen plays a central role in this process by governing the transition between the inactive (Fe^{2+}-NO) and active (Fe^{3+}) states of the catalyst.[5]
These findings reveal how subtle differences in heme coordination selectively govern elementary reaction steps in ferric heme-mediated S-nitrosation and NO-ferroheme formation, processes that may be critically important for the regulation of NO bioavailability.

Acknowledgment We gratefully acknowledge financial support from the National Science Center, Poland for the OPUS Project no. 2019/35/B/ST4/04266.

References

[1] Oszajca, M. Polaczek, J. Rutkowska-Zbik, D. Gurgul, I. Mazuryk, O. Stochel, G. *Chem. Rec.* **2026,** 26:e202500128

[2] Kleschyov, A. L. Zhuge, Z. Schiffer, T. A. Guimarães, D. D. Zhang, G. Montenegro, M. F. Tesse, A. Weitzberg, E. Carlström, M. Lundberg, J. O. *Nat. Chem. Biol*. **2023**, *19*, 1267–1275

[3] Oszajca, M. Jodłowska, A. Kieca, K. Rutkowska-Zbik, D. Stochel, G. *Inorg. Chem*. **2023**, *62*, 5630-5643.

[4] Kieca, K. Rutkowska-Zbik, D. Wierzbicki, S. Kruczała, K. Stochel, G. Oszajca, M. *ChemCatChem*, **2025**, *17*, e00668.

[5] Kieca, K. Stochel, G. Oszajca, M.; *manuscript in preparation*

Molecular Mechanistic Considerations for Ion Hopping in Solid State Soft-Solid Molecular Crystal Electrolytes

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The lithium ion battery market is estimated to be worth more than $200B globally as of 2026, but a major challenge for this industry is safety. Lithium ion battery fires have resulted in lost property, automotive and airplane accidents, and death. Lithium battery fires are typically caused by the explosive decomposition of the organic carbonate liquid electrolyte during an electrochemical battery failure. The replacement of these liquid electrolytes with solid, less- or non-flammable solid electrolytes could mitigate or eliminate this safety concern. Our group has invented a new class of solid electrolyte consisting of "soft" (electron-diffuse, polarizable) ligands templating hard metal ions in network solids containing ion channels. These materials boast the highest conductivity of any class of pure (i.e., non composite) organic solid electrolytes. The mechanism of ion conduction in these materials has been under investigation in our group using a combination of electrochemistry, spectroscopy, microscopy, molecular dynamics simulation, and density functional theory calculations. Conductivity data will be presented in a novel mechanistic/kinetic context, using Arrhenius and Eyring-Polanyi relations so extract information from temperature-dependent conductivity in a manner that has not been exploited in conductive systems to our knowledge.

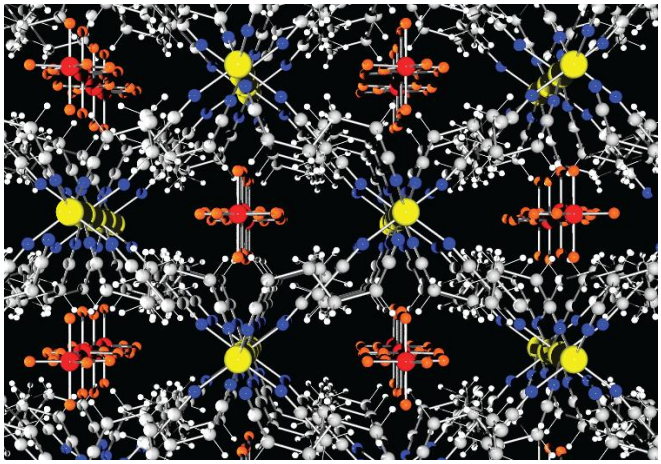

Figure 1.

Interplay between homocysteine, nitric oxide and cobalt porphyrinoids in cobalamin-related processes

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Interactions between vitamin B_{12}, nitric oxide, and endogenous thiols are responsible for important biochemical processes and the regulation of cellular homeostasis. The competition between processes can, to a certain extent, affect the availability of substrates, potentially influencing the state of biological equilibrium. To gain a better understanding of these issues, combined experimental and theoretical studies were conducted on the potential interactions occurring in a three-component system consisting of aquacobalamin, homocysteine, and nitric oxide. The stability of thiolatocobalamins generated in direct reactions depends on the oxygen-controlled redox conditions in the local environment. The observed interchangeability of thiol and NO ligands on the cobalt centre may pose a threat for the course of cobalamin-dependent biological processes. In particular, nitrosative stress can be considered a risk factor for the enzymatic homocysteine methylation, just as cobalamin is for cellular NO homeostasis maintained by endogenous thiols.

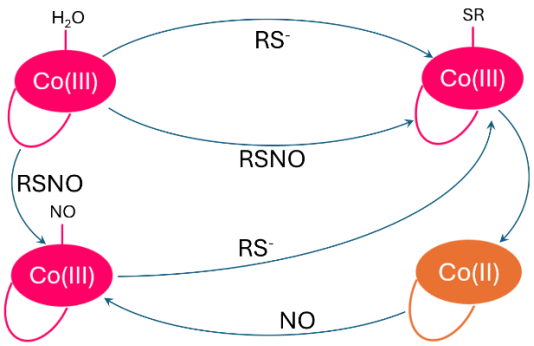

Figure 1. Scheme of the reactions in the aquacobalamin–homocysteine–nitric oxide system occurring under anaerobic conditions

The exceptional reactivity of vitamin B_{12}, expressed in its ability to drive sophisticated enzymatic processes, motivated us to extend our research to other cobalt porphyrinoids. Taking into account the available oxidation states of the cobalt ion and the structural differences among the macrocyclic ligands (corrin, porphyrin, chlorin), we attempted to characterize the determinants of their reactivity toward thiols and nitrosothiols by means of experimentally supported computational methods. The results obtained provide grounds for exploring potential biomedical applications of specific compounds.

Acknowledgment: This study was supported by the National Science Center (Poland) under the grant number 2019/35/B/ST4/04266.

Mechanistic explanation for differences between catalytic activities of dissolved and aerogel immobilized macrocyclic Cu(II) complexes

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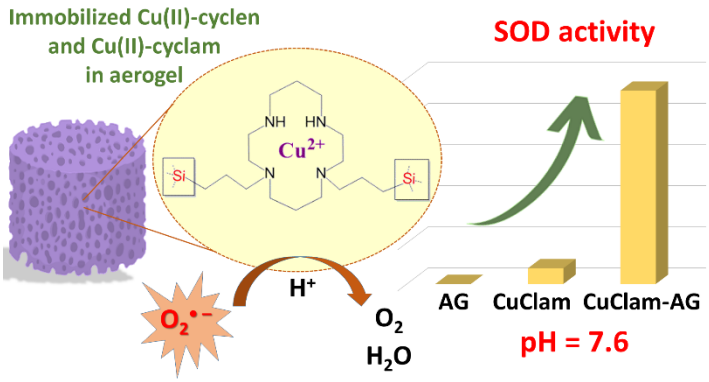
Copper(II) complexes of the tetraazamacrocycles 1,4,7,10-tetraazacyclododecane (cyclen) and 1,4,8,11-tetraazacyclotetradecane (cyclam) were covalently immobilized in mesoporous silica aerogels prepared by the sol–gel method using functionalized silica precursors. The modified macrocyclic ligands were characterized by mass spectrometry (MS) and solution-state nuclear magnetic resonance (NMR) spectroscopy, while the resulting supercritically dried aerogels were investigated by scanning electron microscopy (SEM), N_2 sorption porosimetry, infrared spectroscopy (IR), electron paramagnetic resonance (EPR) spectroscopy, and contrast variation small-angle neutron scattering (SANS). These complementary techniques revealed that the immobilization creates new chemical environments and Cu(II) coordination modes distinct from those in solution, effectively separating the active Cu(II) centers within the nanostructured porous network. The impact of immobilization on catalytic performance was evaluated by examining the H_2O_2-driven oxidation of phenol and the superoxide dismutase (SOD)-mimetic activity of the materials. Fine kinetic studies of phenol oxidation, monitored by capillary electrophoresis and online UV–Vis spectrophotometry, identified hydroquinone, pyrocatechol, and the corresponding benzoquinones as the principal reaction intermediates. Global kinetic modeling demonstrated that immobilization enhances catalyst activation by H_2O_2 but reduces the overall phenol conversion because of hindered mass transport within the porous matrix.[1] In contrast, the immobilized Cu(II) complexes exhibited dramatically enhanced SOD activity compared with their dissolved counterparts. The altered catalytic behavior is attributed to the combined effects of modified Cu(II) coordination, spatial isolation of the catalytic centers, and confinement within the mesoporous silica network. These findings demonstrate that covalent immobilization in silica aerogels provides an effective strategy for tuning the reactivity of Cu(II) macrocyclic complexes and highlight the potential of these functionalized aerogels as robust nanoenzymes for catalytic and antioxidant biomedical applications.[2]



Acknowledgment

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References

[1] Forgács, A. et.al. *Appl. Surf. Sci.* **2022**, *579* 152210.

[2] Lihi, N. et.al. *Appl. Surf. Sci.* **2023**, *611* 155622.

Mechanistic investigations of the metal-catalyzed acrylate radical termination

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Radicals are reactive species of interest in many areas, such as organic synthesis, biochemistry and polymer science, but they have a short life, spontaneously terminating in bimolecular processes by combination (Comb) and/or disproportionation (Disp). While the termination mode is well established for radicals such as primary alkyls, cyanoalkyls, styryl and methacrylates, the preferred termination mode of acrylate radicals is still under debate, some evidence pointing to the prevalence of Disp,[1] other to nearly 100% Comb.[2] The analysis is complicated by the unavailability of a suitable azo derivative, *e.g.* (MeOOC)CH(Me)N=NCH(Me)(COOMe). Thus, investigations have to rely on complex and indirect methods.

We have now investigated the termination of the carbomethoxyethyl radical, •CH(Me)(COOMe), generated by Br-atom abstraction from methyl 2-bromoproprionate (MBP) by either a stronger heteroatom radical (E•, Figure 1**a**) obtained by photolysis of stable E-E precursors (E = $Mn(CO)_5$, $SiMe_3$, $GeMe_3$, $SnMe_3$, Sn^nBu_3, $PbPh_3$), or a copper(I) complex (Figure 1**b**). The investigations show that other phenomena such as radical trapping by E• and H-atom transfer (Figure 1**a**) or catalyzed radical termination (Figure 1**b**) interfere with the spontaneous bimolecular radical termination process, skewing the Disp/Comb ratio. A combination of experimental and DFT mechanistic studies, however, shed new light on this controversial issue.

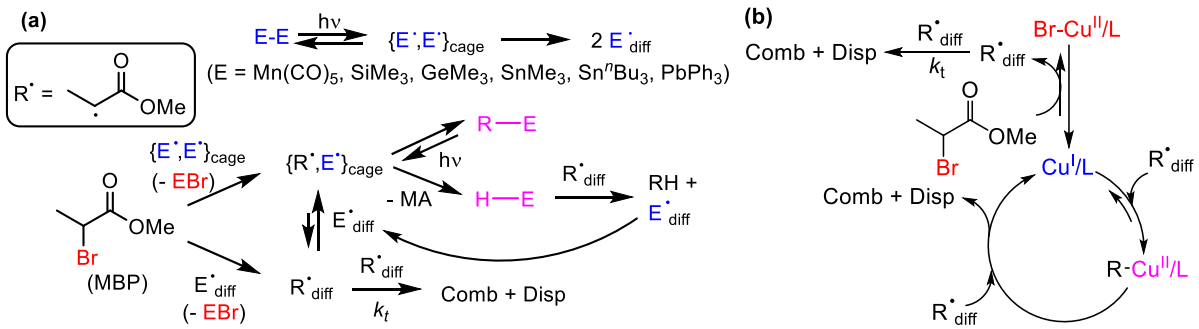

Figure 1. Generation of acrylate radicals by Br-atom transfer from methyl 1-bromopropionate (MBP) to: **a**) metal-based radicals; **b**) diamagnetic Cu^I/L complexes; followed by termination.

Acknowledgment. Funding by project ANR-23-CE06-0001-01 is gratefully acknowledged.

References

[1] a) Bamford, C. H.; Jenkins, A. D., *Nature* **1955,** *176* (4471), 78-78; b) Chaudhuri, A. K.; Palit, S. R. *J. Polym. Sci., Polym. Chem.* **1968,** *6*, 2187-2196; c) Nakamura, Y.; Lee, R.; Coote, M. L.; Yamago, S. *Macromol. Rapid Comm.* **2016**, *37*, 506-513.

[2] a) Bamford, C. H.; Dyson, R. W.; Eastmond, G. C. *Polymer* **1969,** *10*, 885-899; b) Ayrey, G.; Humphrey, M. J.; Poller, R. C. *Polymer* **1977,** *18* (8), 840-844; c) Szablan, Z.; Junkers, T.; Koo, S. P. S.; Lovestead, T. M.; Davis, T. P.; Stenzel, M. H.; Barner-Kowollik, C., *Macromolecules* **2007,** *40* (19), 6820-6833.

Nucleophilic Substitution at Elemental Iodine: Uncovering the Reaction Mechanism

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Nucleophilic substitution (S_N) reactions are unquestionably among the most studied chemical transformations.[1] In organic chemistry, two main categories are typically distinguished based on the molecularity of the reaction: bimolecular S_N2 and monomolecular S_N1 reactions proceed through a single or two consecutive transition states, respectively.[2] The situation becomes markedly different for elements in the third row or below, as S_N reactions usually take place without a distinct activation barrier (no transition state can be found) but proceed through a hypervalent intermediate corresponding to an energy minimum (single-well potential energy surface).[3] In the past decades, this type of reactivity has been established for most main groups, however, surprisingly, the S_N reactivity is rarely described for reaction centres from the halogen group (Group 17). Very recently, a paper opened new directions into the S_N reaction of elemental iodine with imidate anions.[4] However, in contrast to the expected addition-elimination pathway (based on the heavy nature of iodine), a pathway through a central barrier (double-well potential energy surface), analogous to organic reactions, was proposed.

In the present work, we demonstrate that the underlying mechanism is fundamentally different. Using systematic DFT and high-level ab initio calculations, we scrutinised the mechanism of the reaction between I_2 and six representative amide and imidate anions. We show that all these reactions proceed through an energy minimum, corresponding to an intermediate with a hypervalent iodine centre, instead of the proposed central transition state. We show that the overall substitution reactions are thermodynamically disfavoured if solvent effects are neglected (as in the recent work above), and accounting for solvation is crucial for assessing the real thermodynamic aspects of the above reactions. By extending our original scope of nucleophiles to further N-, C-, S- and P-centred anions, we could show that this addition-elimination type S_N2 mechanism is generally operative at elemental iodine. Moreover, we have found that the HOMO energies of the anions are straightforward indicators of their reactivity, and the obtained correlations may be utilised to plan future experiments.

Acknowledgment

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References

[1] Shaik, S. S.; Schlegel, H. B.; Wolfe, S. The S_N2 Reaction. In *Theoretical Aspects of Phisical Organic Chemsitry*; Wiley: New York, 1992.

[2] Yi, Z.; Xu, H.; Yang, J.-L.; Li, J.; Xiao, T.; Chen, H.; Jiang, C.; Li, H.; Lee, S. W.; Hamlin, T. A.; Swart, M.; Bickelhaupt, F. M. *ChemPhysChem* **2018**, *19* (11), 1315–1330., H. J., *J. Am. Chem. Soc.* **2025**, *147* (30), 26889–26897.

[3] a) Lahiri, S. D.; Zhang, G.; Dunaway-Mariano, D.; Allen, K. N. *Science,* **2003**, *299* (5615), 2067–2071. b) van Bochove, M. A.; Swart, M.; Bickelhaupt, F. M. *J. Am. Chem. Soc.* **2006**, *128* (33), 10738–10744.

[4] Yi, Z.; Xu, H.; Yang, J.-L.; Li, J.; Xiao, T.; Chen, H.; Jiang, C.; Li, H.; Lee, S. W.; Fan, H. J., *J. Am. Chem. Soc.* **2025**, *147* (30), 26889–26897.

Multinuclear and multi-frequency NMR investigations of fluoride binding to metal complexes

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Halide recognition by metal complexes represents a major challenge in coordination chemistry, with implications in environmental, biological, and diagnostic fields [1]. In this context, Ln(III)-complexes have proven to be highly valuable tools for halide sensing, thanks to their excellent ability to establish strong interactions with hard anions, combined with their versatile optical and magnetic properties [2, 3].

Here we investigate the interactions between fluoride and a series of metal-complexes (M = Gd(III) and Y(III)) characterized by different structure, coordination geometry, charge and hydration numbers (q = 1 and q = 2), with the aim of determining the influence of the ligand's nature on halide-recognition. By integrating low-resolution multi-frequency NMR approaches with high-resolution multinuclear NMR techniques, we access the magnetic and structural properties of the ternary adducts alongside the thermodynamic and kinetic parameters of the anion-binding events. In particular, the observed reduction in ^{1}H longitudinal relaxation rates upon halide substitution of one coordinated water molecule enabled determining the binding affinity. Water ^{1}H longitudinal relaxation rates vs B_0, and ^{17}O transverse relaxation rates vs T enabled characterizing the magnetic properties and the water exchange dynamics of the ternary chelates. Finally, high-resolution NMR analysis of the diamagnetic Y(III) ternary complexes allowed for structural characterization, while variable temperature ^{19}F NMR spectroscopy enabled measuring the rate constants and activation thermodynamic parameters associated with fluoride binding.

The results of this study represent a step forward in understanding the halides interactions with metal-chelates, which is essential for the rational design of high-performance probes for molecular imaging and anion sensing.

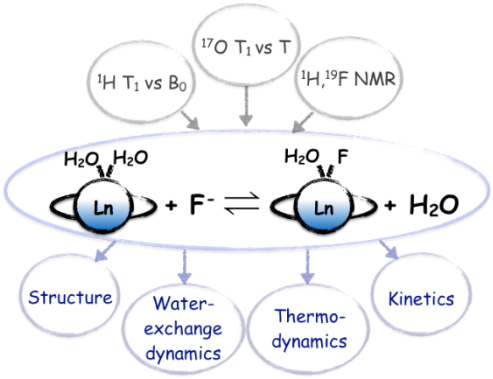

Figure 1. Implemented NMR methods and main outcomes.

References

[1] Bodman, S.E.; Butler. S.J., *Chem. Sci.* **2021.** 12, 2716–2734.

[2] a) Blackburn, O. A. et al., *Angew. Chem.Int.* **2015.** 54, 10783–10786. b) Blackburn, O. A. et al., *Dalton Trans.* **2015.** 44, 19509–19517. c) Blackburn, O. A. et al., *Dalton Trans.* **2016.** 45, 3070–3077.

[3] a) Lalli, D. et al. *Inorg. Chem.* **2022.** 61, 496-506. b) Risolo, L. et al., *Inorg. Chem. Frontiers* **2025.**12, 1187-1199

Digadoglucitol: A New High Relaxivity MRI Contrast Agent Based on the Dimerization of [Gd(HP-DO3A)] and Activated Intramolecular Catalysis of the Prototropic Exchange

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Magnetic resonance imaging (MRI) often relies on Gd(III)-based contrast agents (GBCAs) to enhance image quality by improving differentiation between healthy and diseased tissues. Although GBCAs are generally considered safe, there was a concern about the long-term safety of the GBCAs in the last decade.[1] An alternative strategy is to enhance the efficacy of GBCAs, allowing for a proportional reduction in the administered dose. This can be achieved by improving the parameters that govern GBCA efficacy, quantified as relaxivity (r_{1p} = the increase in the longitudinal relaxation rate of water protons by a 1 mM GBCA solution). Among the possible candidates, there is a growing interest for the GBCAs with labile protons, which can propagate the paramagnetic effect of gadolinium to the bulk via proton exchange processes. In this context digadoglucitol (Fig. 1A), containing two covalently linked [Gd(HP-DO3A)] units via glucamine spacer, was specifically designed to exploit the intramolecular catalysis of the prototropic exchange of the coordinated −OH functions while retaining the attractive physicochemical properties of macrocyclic Gd(III)-complexes. In this work, the thermodynamic, dissociation kinetic, relaxation and structural properties of the digadoglucitol have been studied in detail by pH-potentiometry, spectrophotometry, relaxometry, multinuclear NMR spectroscopy and X-ray diffraction methods. Additionally, pharmacokinetic, biodistribution and MR imaging analysis were investigated in healthy animal models.[2]

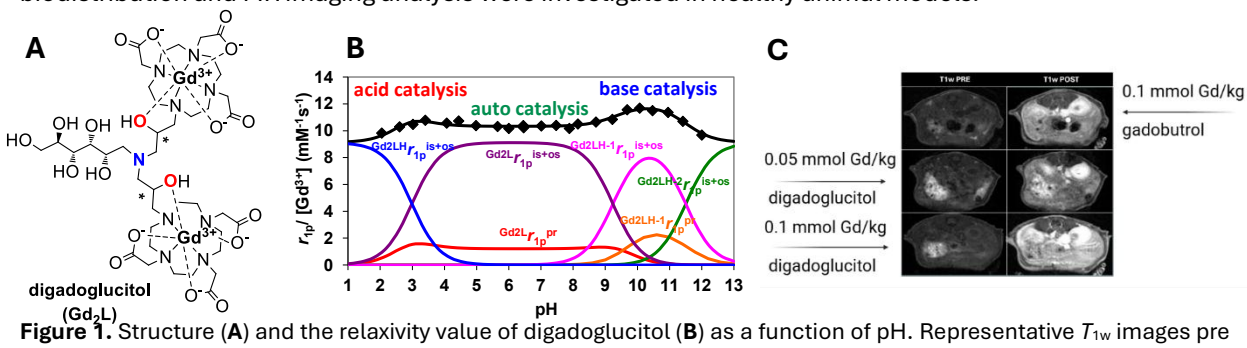

Figure 1. Structure (**A**) and the relaxivity value of digadoglucitol (**B**) as a function of pH. Representative T_{1w} images pre and post contrast administration of [Gd(BT-DO3A)] and Gd_2L (racemic mixture) (**C**), * represents the stereocenters with undefined configuration(B: [Gd_2L]=0.5 mM, 20 MHz, 298K, 0.15 M NaCl)

Gd_2L displays a relaxivity per Gd^{3+} ion 2 to 3 times higher than that of currently used GBCAs by maintaining high thermodynamic stability and kinetic inertness of the parent [Gd(HP DO3A)] close to physiological condition (25°C, 0.15 M NaCl). In aqueous solution, Gd_2L forms multiple diastereomers (36) arising from the chirality of the 2-hydroxypropyl pendants and the SAP/TSAP conformational isomerism of the parent [Gd(HP-DO3A)] (SAP/TSAP ≈ 0.4/0.6). Among these isomers, *RR*, *SS* and *SR*/*RS* are characterized by very similar thermodynamic, kinetic and relaxation properties. The investigation of the relaxivity values as a function of pH reveals that the relaxation enhancement of the Gd_2L arises from the acid-, base- and auto-catalysed proton exchange process of the coordinated -OH functions (Fig. 1B). In particular, the deprotonated glucamine nitrogen acts as a base to catalyze the prototropic exchange of the coordinated −OH groups in the physiological pH range. In vivo MRI experiments demonstrate that digadoglucitol exhibits equivalent level of contrast enhancement when administered at half dose, whereas at equal doses a nearly twofold increase of the signal is observed in a comparison with Gadovist® (Fig. 1C).

References

[1] Kanda, T., et al., *Radiology* **2015**, *276*, 228–232 ; [2] Gazzetto, S., et al., *Chem. & Biomed. Imag.* **2026**, *4*, 571-583

Fluorine Containing Iron Complex as a Redox-Switchable ^{19}F MRI Probe

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Introduction: ^{19}F relaxation is typically slow requiring long repetition times, thus long MRI experiments. Paramagnetic metal ions can largely shorten ^{19}F relaxation times, thereby increasing the ^{19}F MRI signal-to-noise ratio achievable in a given timeframe. Here we explore highly water-soluble, stable and kinetically inert iron complexes formed with small ^{19}F containing ligand as potential ^{19}F MRI probe. We synthesized a CDTA-bisamide derivative ligand possessing two CF_3 moieties and characterized its $Fe^{3+/2+}$ complexes, including equilibrium, dissociation kinetic and redox studies, ^{1}H and ^{19}F relaxation measurements and ^{19}F MRI in phantoms and in mice.

Methods: Ligand synthesis was performed according to a previous protocol.[1] The stability constants of the $Fe^{3+}/^{2+}$ complexes were determined by pH-potentiometry and UV-Vis spectrophotometry. Their kinetic inertness was investigated through ligand exchange reactions under basic conditions and 298 K. ^{1}H r_{1p} relaxivities were measured over a frequency range of 0.01 to 128 MHz, while ^{19}F relaxivities were determined at various temperatures and magnetic fields. The redox properties of the iron complexes were studied through reduction with ascorbate, cysteine and glutathione as well as oxidation by air and H_2O_2, complemented by cyclic voltammetry measurements. ^{1}H and ^{19}F phantom MRI studies were conducted at 7 T, using UTE or FLASH pulse sequences (c_{FeL}= 0.5 -3.0 mM, pH = 7.4). The reduction of $Fe^{3+}L1$ by ascorbate was monitored using ^{19}F phantom imaging. Finally, ^{19}F MR images were recorded following intramuscular injection of $Fe^{3+}L1$ and $Fe^{2+}L1$ into the hind legs of mice using 2D and 3D UTE as well as RARE sequences, respectively.

Results and Discussion: Both FeL complexes exhibit high stability ($\log K_{Fe2+L}$= 12.9(1) and $\log K_{Fe3+L}$= 21.42(1)) as well as pronounced kinetic inertness. The dissociation half-life assessed for $Fe^{3+}L1$ at pH 7.4, determined by transchelation reaction with a 10-fold excess of HBED, was approximately 200 h at 298 K, reflecting higher inertness than that more flexible FeEDTA but lower than for FeCDTA ($t_{1/2}$ = 66 h and 8.9 × 10^4 h, respectively).[2] Transchelation experiments with 2,2'-bipyridine (bpy) at pH 7.36 yielded a half-life of 90 h for $Fe^{2+}L1$. The longitudinal and transverse ^{19}F relaxation times differed markedly between the oxidized (T_1= 2.4(1) and T_2= 1.8(1) ms) and reduced forms (T_1= 71 - 130 and T_2= 60 - 117 ms for different isomers, 9.4 T 298 K). Cyclic voltammetry revealed a single reversible redox $Fe^{3+/2+}L1$ couple with a potential of 240 mV vs. NHE. Both $Fe^{3+}L1$ and $Fe^{2+}L1$ were readily visualized in ^{19}F phantom MRI with short acquisition times and concentration-dependent signal-to-noise ratios. Following intramuscular injection into mice, the two redox forms remained detectable and distinguishable by using appropriate MRI acquisition sequence and parameters. Furthermore, $Fe^{3+}L1$ proved effective as a ^{1}H MRI contrast agent, due to the presence of an inner-sphere water molecule and a relatively high relaxivity ($r_{1p}^{60\ MHz}$ = 2.83, 298 K).[3]

Conclusion: These results demonstrate that relaxation-based discrimination between the reduced and oxidized forms is possible for Fe-based redox-sensitive ^{19}F MRI probes. Such probes hold considerable potential for the detection of oxidative microenvironments associated with inflammation using the $Fe^{2+}L1$ form, as well as hypoxic tumor tissues when employing $Fe^{3+}L1$ chelate.

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References [1] Baranyai, Zs.; Garda, Z.; Kálmán, F. K.; Krusper, L.; Tircsó, Gy.; Tóth, I.; Ghiani, S.; Maiocchi, A.; International Publication Number: WO2016135234A1, **2016;** [2] Baranyai, Zs.; Carniato, F.; Nucera, A.; Horváth, D.; Tei, L.; Platas-Iglesias, C.; Botta, M.;, Chem. Sci., **2021**, *12* (33), 11138; [3] Garda, Z.; Szeremeta, F.; Tóth, Cs. N.; Bunda, Sz.; Pifferi, C; Clémençon R.; Même, S.; Tircsó, Gy.; Tóth, É.;, *J. Am. Chem. Soc.*, **2025**, *147*, 21, 18017.

Field-Dependent ^{1}H Relaxometry as a General Probe of Hydration Dynamics and Metal–Water Exchange in Paramagnetic Ln^{3+} Complexes

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The exchange of inner-sphere water molecules in metal complexes underlies numerous chemical and biological processes and is a key parameter governing the performance of paramagnetic probes for Magnetic Resonance Imaging (MRI) contrast agents.[1] While nuclear magnetic resonance (NMR), particularly ^{17}O NMR, provides a powerful approach to investigate metal–water exchange processes, it typically requires high sample concentrations (for Ln ≠ Gd, generally >50 mM). Such concentration requirements limit the investigation of poorly soluble complexes and supramolecular systems. To overcome these limitations, we present a relaxometric methodology that enables the quantitative determination of inner-sphere water-exchange dynamics in paramagnetic systems under dilute conditions. The method relies on the simultaneous analysis of longitudinal (R_1) and transverse (R_2) ^{1}H relaxation rates over an extended magnetic field range. Because longitudinal relaxivity is primarily governed by the hydration number (q), whereas transverse relaxivity is highly sensitive to the residence lifetime of coordinated water molecules (τ_M), global fitting of R_1 and R_2 data provides quantitative access to both the hydration state and water-exchange kinetics.[2] The methodology was validated using two prototypical series of lanthanide complexes: $[Ln(DTPA)]^{2-}$ and $[Ln(AAZTA)]^{-}$. For the $[Ln(DTPA)]^{2-}$ series (q = 1), relaxometric analysis confirmed the expected acceleration of water exchange across the lanthanide series, with τM decreasing from approximately 340 ns for Pr^{3+} to 2.5 ns for Yb^{3+}. In contrast, the $[Ln(AAZTA)]^{-}$ series exhibited a pronounced slowing of water exchange, with τM increasing from approximately 60 ns for Pr^{3+} to >130 μs for Er^{3+}, Tm^{3+}, and Yb^{3+}, accompanied by a structural transition in the hydration state from q = 2 to q = 1 along the series.[3] The temperature dependence of the relaxometric profiles further enabled the determination of activation parameters for the metal–water exchange process. Positive activation entropies obtained for the investigated Dy^{3+} complexes are consistent with a predominantly dissociative exchange mechanism, providing mechanistic insight into the substitution of coordinated water molecules. Overall, this relaxometric methodology provides a sensitive and experimentally accessible approach for quantifying hydration state and water-exchange kinetics under conditions inaccessible to conventional ^{17}O NMR. By extending the applicability of relaxometric measurements to dilute and poorly soluble paramagnetic systems, it offers a valuable complementary tool for investigating hydration dynamics and substitution mechanisms in coordination chemistry.

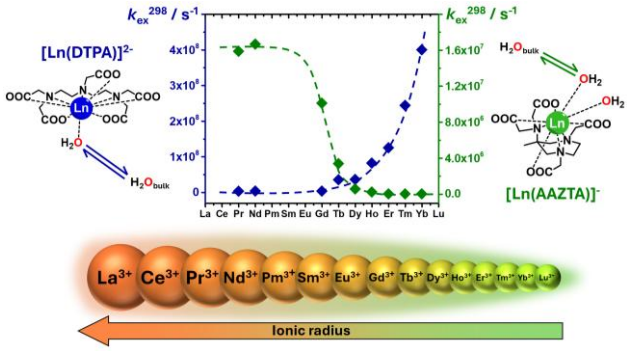

Figure 1. Field-dependent ^{1}H T_1/T_2 relaxometry probes hydration and water exchange across the lanthanide series.

References

[1]Caravan, P., Esteban-Gómez, D., Rodríguez-Rodríguez, A., & Platas-Iglesias, C. (2019). *Dalton Transactions*, *48*(30), 11161-11180.
[2]Pierre, V. C., & Allen, M. J. (Eds.). (2017). *Contrast agents for MRI: experimental methods* (Vol. 13). Royal Society of Chemistry.
[3]Ricci, M., Risolo, L., Carniato, F., Lalli, D., Platas-Iglesias, C., & Botta, M. (2026). *Inorganic Chemistry Frontiers*, *13*(10), 4464-4477.

Polyoxometalate speciation in solution: from mechanistic atlases to antiviral and transport processes

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Polyoxometalates (POMs) are discrete nanomolecular early-transition-metal–oxygen coordination anions whose solution behavior is governed by pH- and concentration-dependent equilibria among condensation, hydrolysis, and redox pathways. Resolving this behavior is essential for understanding POM reactivity, yet it has remained challenging for complex polyanionic systems, where multiple species with distinct nuclearity, protonation state, and oxidation state can coexist and interconvert. This talk presents a systematic approach to mapping these equilibria and traces how the resulting mechanistic insight extends toward redox transformation and, ultimately, functional behavior at membranes.

A speciation atlas approach was developed to address this problem, systematically characterizing the solution behavior of ten archetypal POMs across six structural families and three addenda ion types, compiled from over one thousand NMR spectra recorded under dozens of defined aqueous conditions.[1] This first atlas provides both a species distribution database and a predictive framework for the pH- and concentration-dependent equilibria governing POM speciation, applicable beyond the systems directly studied. The approach was subsequently extended to redox-active molybdenum-based Keplerate-type anions, where it revealed how subtle compositional changes propagate into markedly different stability profiles and fragmentation pathways, offering mechanistic insight into the redox and disassembly chemistry of these high-nuclearity clusters.[2]

These mechanistic foundations also inform the rational design of POM behavior at interfaces: all-inorganic Keggin-type anions were identified as functional molecular carriers across model and cellular membranes via superchaotropic interactions, illustrating how solution-level speciation and reactivity translate into interfacial transport processes.[3] The same superchaotropic properties underpin the antiviral activity of 4−Keggin anions against human coronavirus HCoV-OC43, where cluster integrity under assay conditions proves to be a prerequisite for potency and charge emerges as an independent mechanistic determinant.

Together, these findings demonstrate how rigorous, mechanism-focused characterization of POM solution chemistry — spanning equilibrium speciation, redox pathways, and interfacial reactivity — provides a framework for predicting and rationally directing POM behavior in complex media.

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References

[1] N. I. Gumerova, A. Rompel, *Sci. Adv.* **2023**, *9*, eadi0814, doi: 10.1126/sciadv.adi0814.

[2] I. Gregorovic, N. I. Gumerova, A. Rompel, *Sci. Adv.* **2025**, *11*, eaea1910, doi: 10.1126/sciadv.aea1910.

[3] A. Barba-Bon, N. I. Gumerova, E. Tanuhadi, M. Ashjari, Y. Chen, A. Rompel, W. M. Nau, *Adv. Mater.* **2024**, 2309219, doi: 10.1002/adma.202309219.

Substitution reactions of the weak Lewis pair H_3P-$AlCl_3$: mechanistic insights

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Phosphine (PH_3) is a highly toxic and poorly functionalizable molecule, which severely limits its direct use in chemistry. The Grützmacher group (ETH Zürich) recently described a Lewis-acid-assisted strategy that enables efficient monosubstitution of PH_3 under mild conditions.[1] In the presence of aluminum chloride, PH_3 forms a labile $H_3P \rightarrow AlCl_3$ Lewis pair that readily reacts with alkyl halides in organic solvents, affording primary phosphines within minutes at room temperature. Experimental observations demonstrate the broad applicability of this approach, including the synthesis of sterically demanding phosphines such as adamantyl- and *tert*-butylphosphine, as well as the scalability to kilogram quantities for selected substrates.

Our density functional theory (DFT) calculations reveal that the weak P–Al interaction facilitates dissociation upon contact with alkyl chlorides, enabling a Lewis-acid-assisted nucleophilic attack that proceeds via formation of the phosphonium salt $[R–PH_3]^+[AlCl_4]^–$. According to our mechanistic analysis, while *tert*-butyl chloride reacts via an S_N1 pathway due to the stability of the *tert*-butyl carbocation, adamantyl chloride undergoes a unique S_N2-type substitution with a so-called frontside attack, reflecting the inability of the adamantyl framework to invert at its C center. Further comparative studies on methyl chloride and *endo*-norbornyl bromide provide additional insight into reaction pathways.

Acknowledgment

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References

[1] Oswald, J.; Fekete, C.; Baker, M.; Bispinghoff, M.; Pringle, P. G.; Weferling, N.; Benkő, Z.; Grützmacher, H. *Angew. Chem.*, Int. Ed. **2025**, *64*, e202501656.

Dinitrogen activation and functionalization mediated by metal complexes

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Ammonia plays a key role in modern society and its production is expected to increase in the future. Given the importance of the N-fixation process, the field of dinitrogen organometallic chemistry is broad and rich.[1,2,3] Nevertheless, homogeneous catalysts for efficient ammonia synthesis remain scarce in the literature. The intrinsic instability of some species involved and the combination of strong reductant and acid often required in these systems, make H_2 evolution a central issue in ammonia synthesis. Our study on the protonation of a triphospine nitride Molybdenum complex obtained from dinitrogen splitting in mild conditions,[4] reveals a new mechanistic pathway which allows ammonia production in stoichiometric amounts, without the implication of an external electron source. This mechanism involving H atom transfer as the key step, is supported by a range of experimental data, and corroborated by DFT calculations (**Figure 1**). Importantly, this novel mechanistic understanding allows to prevent H_2 formation, and development of a catalytic process is now under investigation.[5]

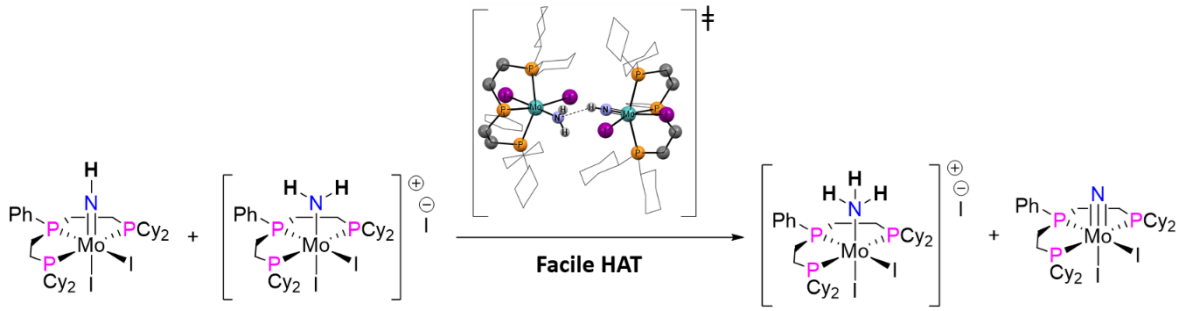

Figure 1. Key step for NH_3 formation upon protonation in the mechanism presented.

References

[1] Kim, S.; Loose, F.; Chirik, P. J., "Beyond Ammonia: Nitrogen–Element Bond Forming Reactions with Coordinated Dinitrogen", *Chem. Rev.* **2020**, *vol. 120, no. 12,* pp. 5637–5681.
[2] Chalkley, M. J.; Drover, M. W.; Peters, J. C., "Catalytic N_2 -to-NH_3 (or -N_2H_4) Conversion by Well-Defined Molecular Coordination Complexes", *Chem. Rev.* **2020**, *vol. 120, no. 12,* pp. 5582–5636.
[3] Tanabe, Y.; Nishibayashi, Y., Comprehensive insights into synthetic nitrogen fixation assisted by molecular catalysts under ambient or mild conditions", *Chem. Soc. Rev.*, **2021**, *vol. 50, n. 8*, pp. 5201–5242.
[4] a) Liao, Q.; Saffon-Merceron N.; Mézailles, N., "N_2 Reduction into Silylamine at Tridentate Phosphine/Mo Center: Catalysis and Mechanistic Study", *ACS Catal.* **2015**, *vol. 5, no. 11,* pp. 6902–6906. b) Liao, Q.; Cavaillé, A.; Saffon-Merceron N.; Mézailles, N., "Direct Synthesis of Silylamine from N_2 and a Silane: Mediated by a Tridentate Phosphine Molybdenum Fragment", *Angew. Chem.* **2016**, *vol. 128, no. 37,* pp. 11378–11382. c) Espada, M. F.; Bennaamane, S.; Liao, Q.; Saffon-Merceron N.; Massou, S.; Clot, E.; Nebra, N.; Fustier-Boutignon, M.; Mézailles, N., "Room-Temperature Functionalization of N_2 to Borylamine at a Molybdenum Complex", *Angew. Chem.* **2018**, *vol. 130, no. 39,* pp. 13047–13050.

Lifting The Lid on Iron-Catalysed Reductive Alkyl-Alkyl Cross-Couplings

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Transition metal catalysed alkyl-alkyl bond formation, *via* cross-coupling, plays an important role in the organic synthesis toolkit. Despite considerable progress in recent years, iron's utility in this area has remained stunted due to a reliance on organometallic substrates, such as Grignard reagents, which bring with them functional group incompatibilities.[1] The emerging field of iron-catalysed reductive cross-couplings aims to circumvent this issue *via* the use of "mild" reducing agents to generate reactive iron intermediates.[2,3] Examples of iron-catalysed reductive cross-couplings remain limited with no molecular level mechanistic insights into iron speciation contributing to their slow development. Such insights would permit design principles to be established for efficient alkyl-alkyl bond formation, in turn, advancing method development. Towards this goal, the current study presents the first detailed mechanistic investigation into an iron-catalysed reductive cross-coupling between alkyl halides and olefins first reported in 2023 by G. C. Fu and co-workers (Figure 1).[2] Using Mössbauer, NMR and EPR spectroscopies, supported by solid state-structures *via* single-crystal X-ray crystallography, iron speciation present during catalysis and their role in the catalytic cycle elucidated. Combined with detailed computational calculations, these studies have established the catalytic cycle for this reaction enabling the rational design of future iron-catalysed reductive cross-coupling methodologies.

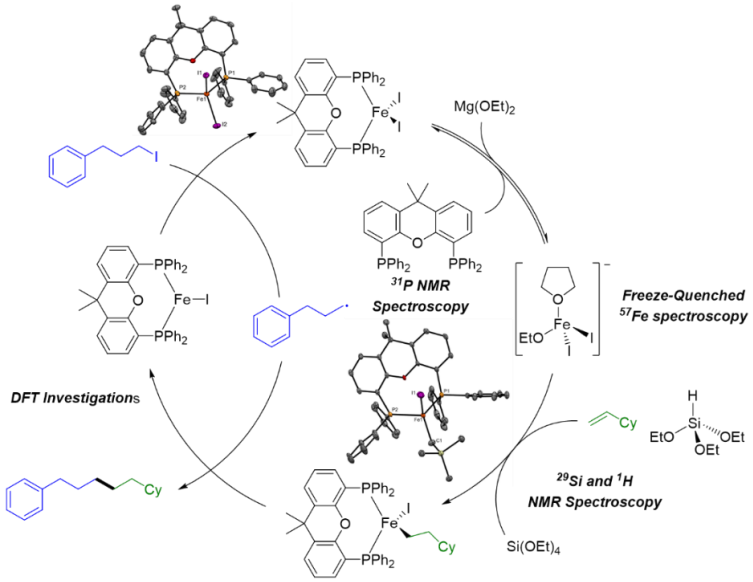

Figure 1. Working catalytic cycle for the reductive cross-coupling between alkyl halides and olefins with experimental evidence to support speciation and reactivity.[2]

References

[1] Hatakeyama, T. *et al.* Iron-Catalyzed Alkyl–Alkyl Suzuki–Miyaura Coupling. *Angew. Chem. Int. Ed.* **51**, 8834–8837 (2012).

[2] Tong, X., Yang, Z.-P., Del Angel Aguilar, C. E. & Fu, G. C. Iron-Catalyzed Reductive Cross-Coupling of Alkyl Electrophiles with Olefins. *Angew. Chem. Int. Ed.* **62**, e202306663 (2023).

3. Wang, Q. et al. Iron-catalysed reductive cross-coupling of glycosyl radicals for the stereoselective synthesis of C-glycosides. Nat. Synth. 1, 235–244 (2022).

Catalytic application of *P,C,P*-Ge and Sn chelate complexes in CO_2 activation

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One of the main research directions of modern main group organometallic chemistry is the replacement of transition metals by p-field metals in the activation of small molecules and catalytic transformations. In an international collaboration with the research group of Libor Dostál, I have investigated the reactivity of *P,C,P*-Ge, and Sn complexes using computational chemistry methods. The *P,C,P*-SnH complex proved to be a selective catalyst for CO_2 activation and hydroboration reactions. (Figure 1, **A**, and **B**) It is important to emphasize that although the reaction leading to pinacol formate proceeds under mild conditions, it is relatively slow, as my calculations support. Moreover, in accordance with the calculated high barriers, the Ge analog is unreactive. I have found that the hydroboration reaction is kinetically controlled, which also explains the high selectivity of pinacol formate formation. I have also mapped the reaction pathways leading to the minor products: bis(boryl)oxide, methoxy borane, and bis(boryl)acetal (Figure 1, **C**, **D**, and **E**).

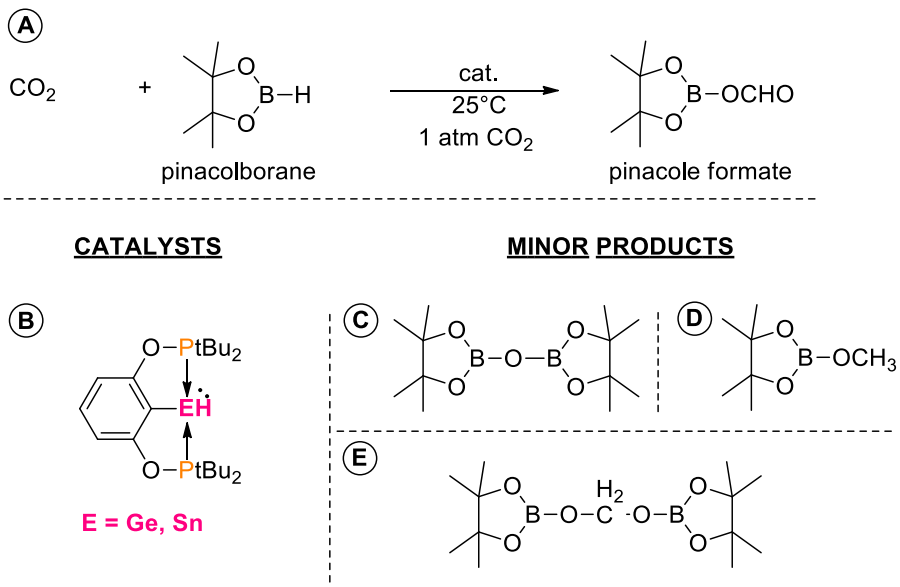

Figure 1. The investigated CO_2 insertion and hydroboration reaction

References

[1] Chlebík, R.; Kertész, E.; Erben, M.; Růžička, A.; Jambor, R.; Benkő, Z.; Dostál, L.: Remarkable coordination variability of the P,C,P-pincer ligand in organotin(IV) compounds – a promising outlook for other p-block elements. *Dalton Trans.* **2025**, 54, 15093-15106.

[2] Chlebík, R.; Kertész, E.; Růžičková, Z., Růžička, A.; Jambor, R.; Benkő, Z.; Dostál, L.: Straightforward Donor Atom Switching: From P,C,P- to Various Y,C,Y-Pincer (Y = O, S, Se) Organotin(IV) Compounds and Cations. *Inorg. Chem.* **2026**, 65, 17, 9372–9389.

Rigid 8-Hydroxyquinoline-Functionalized Macrocyclic Chelators for Mn(II): Thermodynamic, Relaxometric, and Kinetic Studies

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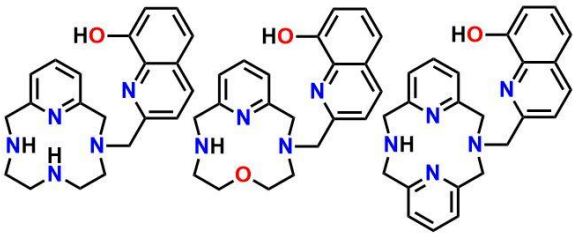

Figure 1. Structures of the 3-PCOX, 3-OPCOX and 3-BPOX ligands

As a leading non-invasive diagnostic modality in modern medicine, magnetic resonance imaging (MRI) is widely used worldwide. To improve image quality and diagnostic performance contrast agents (CAs) are routinely applied in a large proportion of clinical examinations. However, concerns regarding the potential release of toxic Gd(III) ions have prompted the search for essential metal ion based alternatives to Gd(III)-based CAs.[1] Consequently, considerable research efforts have focused on the development of Mn(II), Fe(II), and Fe(III)-based MRI CA candidates.[2,3] The well-known bidentate 8-hydroxyquinoline moiety has frequently been incorporated as a pendant group in the design of both linear and macrocyclic chelators. In our recent study we demonstrated that functinalization of the macrocyclic N-atom located *cis*- to the pyridine nitrogen in 1,4,7,10-tetraaza-2,6-pyridinophane (pyclen) with an 8-hydroxyquinoline pendant arm (3-PCOX) creates a highly favorable environment for Mn(II).[4] To further enhance the rigidity of the ligand framework, two additional derivatives were designed by replacing the N-atom at the 6-position of the pyclen scafold with either an ether oxygen (3-OPCOX) or a fused pyridine ring (3-BPOX). This poster presents the synthesis of these novel ligands together the thermodynamic stability constants of their complexes formed with Mg(II), Ca(II), Mn(II), Cu(II), and Zn(II) ions. Furthermore, the proton relaxivities of the Mn(II) complexes are reported and their kinetic inertness is evaluated by examining transmetalation reactions with Cu(II) and Zn(II) ions.

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References

[1]Tircsó, Gy.; Brücher, E.; Baranyai, Zs.; Kálmán, F. K.; Tóth, I., *Magy. Kém. Foly.* **2017**, *123* (2), 82-93.

[2]Gale, E. M.; Atanasova, I. P.; Blasi, F.; Ay, I.; Caravan, P., *J. Am. Chem. Soc.* **2015**, *137* (49), 15548-15557.

[3]Adams, L. C.; Jayapal, P.; Ramasamy, S. K.; Morakote, W.; Yeom, K.; Baratto, L.; Daldrup-Link, H. E., AJR *Am. J. Roentgenol*. **2023**, *220* (4), 590-603.

[4]Kapus, I.; Lihi, N.; Váradi, B.; May, N. V.; Bunda, Sz.; Kálmán, F. K.; Green, K. N.; Tircsó, Gy., *Inorg. Chem*. **2026**, accepted article

Metal Coordination as a Tool for Controlling Azo Thermal Isomerization Pathways

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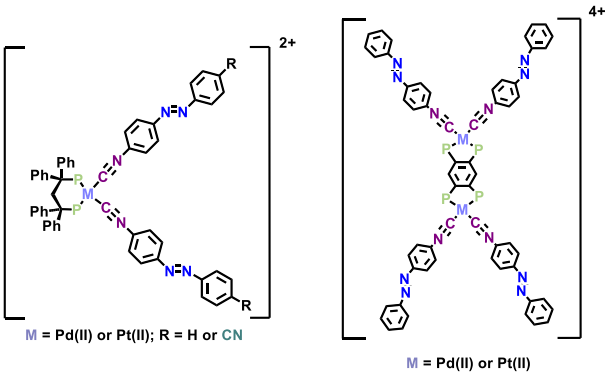
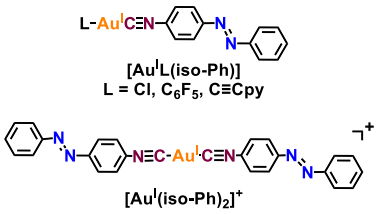
Azobenzene and its derivatives constitute one of the most extensively studied families of molecular photoswitches owing to their ability to undergo reversible *E*↔*Z* photoisomerization. The thermal back-isomerization process *Z*→*E* has been widely investigated given the fact that is athe tunable process for the time-switching reaction and is generally accepted to proceed through either rotational or inversion pathways.

One of the lines of study in the grup *Mecanismes de Reacció* from the University of Barcelona is to investigate the effect of metal coordination on the thermal *Z*→*E* isomerization of azo-functionalized ligands.

The initial systems here presented that have been studied are those of square-planar Pd(II) and Pt(II) complexes bearing two or four azo ligands (on dinuclear species) in a *cis* isomeric geometrical distribution. In all cases, the results show that there is a complete absence of cooperative effects in the photothermal response of the systems, despite the presence of multiple photoactive units. Furthermore, coordination to the cationic metal centres has been found to promote a charge separation in the transition state, thus favouring a rotational isomerisation mechanism.



From this point, we have focused the studies on linear Au(I) complexes bearing and azo-functionalized isocyanide ligand. Again, the kinetico-mechanistic analyses reveal that π-backdonation from the d^{10} Au(I) centre to the vacant π* orbitals of the isocyanide group of the ligand contributes favouring a charge-separated transition state. Remarkably, in complexes containing two isocyanide ligands in a *trans* isomeric distribution, the competition for such π-backdonation promotes a mechanistic switch from a rotational to an inversional transition state.



As a whole, the measure of the activation volumes ($\Delta V^{\ddagger}$) determined for all the systems proved to be a clear handle of the systematic tuning *via* modification of the electronic distribution of the transition state due to metal complexation.

References

1 O. Raïch Panisello, J. Jover, C. Puigjaner, M. Ferrer and M. Martínez, Inorg. Chem., 2024, 63, 16251–16263.
2 O. Raïch Panisello, J. Jover, C. Puigjaner, M. Ferrer and M. Martínez, *Dalton Trans.*, 2025, 54, 15134–15143.

Poster presentations

Thermodynamic and Kinetic Evaluation of NOTA-NP, a possible Mn(II)-based liver-specific probe

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Magnetic resonance imaging (MRI) is a non-invasive imaging technique that provides high-resolution images of soft tissues without ionizing radiation. Its diagnostic performance can be enhanced by organ-specific contrast agents (CAs), especially liver-targeted probes, owing to the central role of the hepatobiliary system in metabolism and detoxification. Recent efforts have focused on Mn(II)-based CAs (MnBCAs) as alternatives to GBCA, aiming to improve biocompatibility while enabling targeted imaging. Their successful application relies on high thermodynamic stability and kinetic inertness to prevent dissociation or transmetallation by endogenous metals such as Cu(II) and Zn(II).[1] Recently, the NOTA-NP ligand has been proposed as the basis of a liver-specific Mn(II)-based MRI probe exhibiting biodistribution similar to that of the clinically used Gd(DTPA-EOB), together with promising liver accumulation and contrast enhancement; however, its thermodynamic and kinetic properties have not yet been investigated.[2] This study provides a comprehensive evaluation of its thermodynamic stability, kinetic inertness, and relaxation properties.

The NOTA-NP ligand shows reduced basicity and forms a Mn(II) complex with lower thermodynamic stability (Σ_i^4 log K_i^H=22.31(6), log K_{MnL}=10.16(2), and pMn=6.56) compared to its parent counterpart Mn(NOTA) (Σ_i^4 log K_i^H=24.0, log K_{MnL}=16.30, and pMn=7.77).[3] The favorable in vivo behavior of Mn(NOTA-NP) is likely due to the naphthalene moiety, which promotes hepatobiliary uptake. However, incorporation of this moiety decreases the ligand's basicity and compromises Mn(II) complex stability. Kinetic studies revealed rapid transmetallation in the presence of 10- and 25-fold excess of Zn(II) and Cu(II) under pseudo-first-order conditions, with equilibrium reached within less than 5 minutes. This high lability raises significant safety concerns. Despite its limited inertness, the relaxivity of the Mn(NOTA-NP) probe (r_{1p}/r_{2p}=2.56/4.79 at 25°C, 1.41 T) was significantly higher than that of the parent Mn(NOTA) complex (r_{1p}=1.1 at 25°C, 1.41 T).[5] The higher relaxivity of Mn(NOTA-NP) is most likely attributable to the presence of one coordinated inner-sphere water molecule, which is absent in Mn(NOTA). These findings reveal a trade-off in designing liver-specific Mn(II)-based MRI probes; adding a naphthalene moiety improves targeting and relaxivity but reduces thermodynamic stability and kinetic inertness. Future designs should aim to preserve liver-targeting ability while improving thermodynamic stability and kinetic inertness.

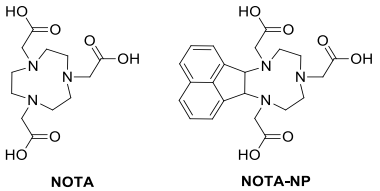

Figure 1. Formulae of the NOTA and NOTA-NP ligands.

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References

[1] Pan, D.; Schmieder, A. H.; Wickline, S. A.; Lanza, G. M. *Tetrahedron*. **2011**, *67* (44), 8431–8444.

[2] Islam, Md. K.; Baek, A.-R.; Yang, B.-W.; Kim, S.; Hwang, D. W.; Nam, S.-W.; Lee, G.-H.; Chang, Y. *Pharmaceuticals* **2023**, *16* (4), 602.

[3] Madarasi, E.; Marlin, A.; Kálmán, F. K.; Esteban-Gómez, D.; Cordier, M.; Tripier, R.; Platas-Iglesias, C.; Tircsó, G.; Patinec, V. *Inorg. Chem.* **2025**, *64* (32), 16594–16607.

[4] Geraldes, C. F. G. C.; Sherry, A. D.; Brown, R. D.; Koenig, S. H. *Magnetic Resonance in Med.* **1986**, *3* (2), 242–250.

SOD and catalase-like activities of a NiSOD related metallopeptide

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In aerobic biological systems, redox processes generate reactive oxygen species (ROS). An imbalance favoring ROS accumulation results in oxidative stress. Among these species, the superoxide anion radical ($O_2^{\bullet-}$) is one of the most important. Superoxide dismutases (SOD) are a dedicate class of enzyme family which are capable of catalyzing the decomposition of superoxide anion radical in the extracellular matrix.[1] One of them is the nickel-containing SOD enzyme, where the nickel is in the active center of the enzyme. The dismutation reaction occurs through a proton-coupled electron transfer mechanism accompanied by the change of oxidation state of nickel between +2 and +3. The NiSOD enzyme is a homohexamer and each nickel center is catalytically active. X-ray crystallography revealed thet the active sites of the enzyme are located at the N-terminal part of the identical peptide chains where the nickel ions are in a unique coordination environment. In the reduced form of the enzyme, nickel(II) is coordinated *via* the terminal amino group, the first peptide nitrogen as well as the two thiolate groups of cysteine residues in a square-planar coordination environment. Oxidation of nickel(II) to nickel(III) results in the binding of the imidazole-N of the terminal histidine in the apical position, leading to the formation of a square-pyramidal coordination environment. This coordination motif exhibits a loop which is termed a NiSOD binding hook.[2] In this study, we explore the effect of N-methylation of the N-terminal amine on the structural, thermodynamic, spectroscopic and SOD activity properties of metallopeptide models that mimic the active site of NiSOD.

The nickel(II) and nickel(III) complexes of the N-methylated NiSOD fragment exhibits thermodynamic and spectroscopic properties that closely resemble those of the native NiSOD fragment. However, investigation of its superoxide dismutase (SOD) activity provides new insights into the reaction mechanism between NiSOD and the superoxide anion radical. The reaction of the nickel(II) complex with superoxide revealed a considerably more complex mechanism than previously proposed for NiSOD fragments. Although NiSOD and its catalytically active fragments have traditionally been regarded solely as superoxide dismutase mimics, our results demonstrate that the metallopeptide simultaneously catalyzes the decomposition of hydrogen peroxide. Since hydrogen peroxide is continuously generated during superoxide dismutation, it immediately initiates a second catalytic cycle in which both Ni(II) and Ni(III) participate in catalase-like activity. Consequently, the observed catalytic behavior cannot be described by a single SOD catalytic cycle but instead requires two simultaneously operating catalytic cycles. This coupling between SOD- and catalase-like reactions has not previously been considered for metallopeptides mimicking NiSOD.[3]

Acknowledgment

This project was funded by the NKFIH STARTING25-152343 garnt. N. L. acknowledges financial support of the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

References

1. Sheng, Y.; Abreu, I. A.; Cabelli, D. E.; Maroney, M. J.; Miller, A. F.; Teixeira, M.; Valentine, J. S., Superoxide dismutases and superoxide reductases. *Chem Rev* **2014,** *114* (7), 3854-918.
2. Barondeau, D. P.; Kassmann, C. J.; Bruns, C. K.; Tainer, J. A.; Getzoff, E. D., Nickel superoxide dismutase structure and mechanism. *Biochemistry* **2004,** *43* (25), 8038-47.
3. Dóra, B.-K. D., Angyal; Nóra Veronika, May; István, Fábián; Norbert, Lihi, Beyond superoxide dismutation: dual superoxide dismutase and catalase-like activities of a nickel containing superoxide dismutase enzyme fragment. 2026.

Resorcinol–formaldehyde–gelatin aerogel for the selective removal of aqueous Au(III) ions

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The increasing volume of electronic waste and the growing demand for sustainable recovery of critical raw materials have intensified the need for efficient sorbents for precious metal recycling.[1] In this work, environmentally friendly hybrid resorcinol-formaldehyde-gelatin (RFG) aerogels were developed and optimized for the selective sorption and recovery of Au(III) ions from complex aqueous media. The aerogels were synthesized through the polycondensation of resorcinol and formaldehyde in the presence of varying amounts of gelatin, followed by solvent exchange and supercritical CO_2 drying.[2] Structural characterization by SEM, FT-IR, and solid-state NMR confirmed the formation of chemically integrated hybrid networks with open meso- and macroporous structures favorable for rapid mass transfer. The sorption performance of the materials was systematically investigated as a function of composition, pH, temperature, and metal-ion concentration. The results demonstrated that gelatin plays a crucial role in Au(III) binding, with sorption capacity increasing with gelatin content up to an optimum composition. The best-performing sorbent, RFG22, containing 22 wt% gelatin and prepared without acid catalyst, exhibited a maximum Au(III) sorption capacity of approximately 650-670 mg g^{-1} according to the Langmuir model. Furthermore, the aerogel showed outstanding selectivity toward Au(III) in the presence of fifteen competing metal ions, even when the interfering ions were present at substantially higher concentrations. To understand the sorption mechanism, fluorescence spectroscopy, FT-IR, solid-state NMR, and XPS analyses were performed. The results indicated that both the gelatin component and the resorcinol-formaldehyde framework participate in Au(III) binding, while the RF network appears to play a dominant role in the reduction of Au(III) to Au(I). Regeneration studies revealed nearly quantitative gold recovery using thiourea-based eluents, enabling repeated sorbent reuse. The practical applicability of the developed material was successfully demonstrated through selective gold recovery from real electronic-waste leachates, including solutions obtained from acid digested mobile phones. Overall, the developed RFG aerogels combine outstanding stability under strongly acidic conditions, exceptionally high sorption capacity, remarkable selectivity, efficient regeneration, and promising scalability, making them attractive candidates for sustainable gold recovery and circular resource utilization.

Acknowledgment

The project was funded by the EKÖP-25-2 grant.

References

[1] Ben Abdelhamid et al., Environ. Model. Assess., 2025, 30, 857–869.

[2] Boccia et al., Gels, 2023, 10(1), 32.

The chemical characterization of paramagnetic metal complexes containing malonate pendants

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Nowadays, the MRI contrast agents used in clinical practice are the complexes of paramagnetic Gd(III) ion formed with polyamino-polycarboxylate ligands.[1] The in vivo application of the toxic Gd(III) ion was facilitated by the formation of thermodynamically stable and inert complexes, which were considered to be safe for years until the appearance of the nephrogenic systemic fibroses (NSF) in the late 90's.[2] This potentially lethal disease was mostly reported for patients having severe renal failure, when the urine excretion is slower or stopped, thus the in vivo life-time of the CAs increases significantly, which can lead to the liberation of the Gd(III) from the agents.[3] Due to the "NSF-problem", concerns have been raised over the safety of contrasted MRI investigations, which prompted researchers to find alternatives for the compromised CAs.

In this work, we present the results of the physico-chemical characterization of two O-pyclen and bis-pyclen based Gd(III) complexes containing malonate pendant arms linked to the amine donor atoms of the macrocyclic backbone (OPDMA, and BPDMA).[4]

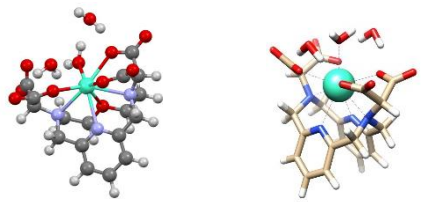

Figure 1. Calculated structures of the $[Gd(OPDMA)(H_2O)]^-$ and $[Gd(BPDMA)(H_2O)]^-$ complexes.

The results show that the $[Gd(OPDMA)]^-$ and $[Gd(BPDMA)]^-$ complexes possess high thermodynamic stability and remarkable kinetic inertness, with a dissociation half-life of 3.2 years at physiological conditions. The complexes exhibit fast water exchange rate (k_{ex}^{298} = 73 × 10^6 s^{-1} and 43 × 10^6 s^{-1}, respectively), which is attributed to the steric compression near the water coordination site. These properties render the chelates promising candidates for MRI contrast agent development. DFT calculations confirmed the q = 1 coordination mode and revealed that one carboxylate donor remains uncoordinated in the $[Gd(OPDMA)]^-$. The dissociation of the investigated chelates is orders of magnitudes faster than $[Gd(DOTA)]^-$, while their inertness is almost identical. However, their 3.2 years half-lives under physiological conditions are orders of magnitude higher than the values characterizing the linear MRI contrast agents. In summary, we can conclude that the two complexes possess excellent physico-chemical properties, which make them suitable even for *in vivo* applications.

Acknowledgment

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References

[1] Helm, L.; Merbach, A.R.; Tóth, É., The Chemistry of Contrast Agents in Medical Magnetic Resonance Imaging, Second edition, 2013;
[2] Weinmann, H. et al., *Am. J. Roentgenol*. **1984**, *142*, 619-624;
[3] Grobner, T., *Nephrol. Dial. Transplant.* **2006**, *21*, 1104-1108;

Catalytic properties of symmetric and asymmetric Rh(I)-N-heterocyclic carbene complexes in nitrile hydration

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Organometallic Rh(I)-N-heterocyclic carbene complexes are widely used as catalysts yet they have rarely been used to catalyze nitrile hydration in aqueous or partially aqueous systems. To date, only a few rhodium catalysts have been reported for this transformation.[1]

We present the synthesis, catalytic properties and crystal structures of NHC ligand chloride and hexafluorophosphate salts and their corresponding Rh(I)-NHC complexes. [RhCl(cod)(NHC)] (cod = η^4-cyclo-1,5-diene; NHC = N-heterocyclic carbene) type complexes were synthesized in a simple, one-step synthetic method without formation of the free NHC ligands or Ag(I)-NHC transmetalation complexes. We utilize $[RhX(cod)]_2$ ($X=Cl^-$, OH^-) metal precursor, the respective imidazolium/imidazolinium salts, and K_2CO_3 as a mild base and deprotonating agent. The symmetric[2] and asymmetric Rh(I)-complexes were synthesized in good yield using the "classical" solvent based method in toluene at 70 °C and with solvent-free mechanochemical grinding in a planetary ball mill. All synthetic reactions were carried out under ambient air. The compounds were characterized in solution by ^1H and ^{13}C NMR spectroscopy. Furthermore, their solid-state molecular structures were determined by single crystal X-ray diffraction (SCXRD).

The hydration of nitriles to amides is a 100% atom economy reaction but is hindered by selectivity issues. The rhodium(I)-NHC complexes were efficiently used as selective catalysts for the transformation of nitriles to amides in 50% aqueous 2-propanol mixtures in air, without the use of an inert atmosphere[2] (up to TOF = 276 h^{-1}). The hydration of nitriles proceeds efficiently for a wide range of aromatic and heteroaromatic nitriles.

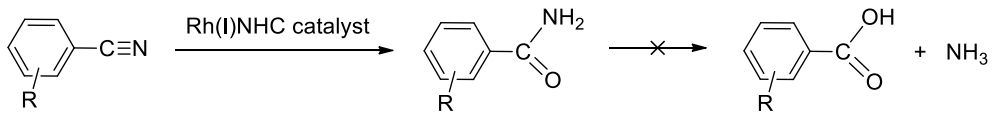

Figure 1. General scheme of catalytic transformation of benzonitriles to benzamides

Acknowledgment

The authors are grateful for Financial support from project no. RRF-2.3.1-21-2022-00009, titled National Laboratory for Renewable Energy, has been provided by the Recovery and Resilience Facility of the European Union within the framework of Programme Széchenyi Plan Plus, which is gratefully acknowledged. A.U. is grateful for the general support of János Bolyai Research Scholarship.

References

[1] a) Djoman, M.C.K.B.; Ajjou, A. N.*Tetrahedron Lett.* **2000**, *41*, 4845–4849. b) Goto, A.; Endo, K.; Saito, S. *Angew. Chem. Int. Ed.* **2008**, *47*, 3607–3609. c) Daw, P.; Sinha, A.; Rahaman, S.M.W.; Dinda, S.; Bera, J.K. *Organometallics* **2012**, *31*, 3790–3797. d) Tomás-Mendivil, E.; García-Álvarez, R.; Vidal, C.; Crochet, P.; Cadierno, V. *ACS Catal.* **2014**, 4, 1901–1910.

[2] Czégéni, C.E.; De, S.; Udvardy, A.; Derzsi, N.J.; Papp, G.; Papp, G.; Joó, F. *Catalysts.* **2020**, *10* (1), 125.

Experimental design and optimization: Hydrogen storage in ammonia borane via aqueous media

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To ensure that hydrogen gas can be stored properly and then used as a fuel, we need to find the most cost-effective and efficient storage method. Storing hydrogen by forming chemical bonds offers us such an option, as this type of system can be stored for years without losing activity.

Our group is actively studying the field of homogeneous catalytic hydrogen storage in aqueous media using various H_2 vectors (HCOOH, NH_3BH_3). In our previous work, we proved that various transition metal (Ir[1], Ru[2], Rh) phosphine complexes are excellent for hydrogen storage in formic acid; however, we expanded our research to studies ont he application of ammonia borane.

In our recent research, we studied hydrogen generation from NH_3BH_3 based on a previously defined experimental design, using transition metal complexes-primarily Ir-, Ru-, Rh-, Pd[3], és Mn-complexes.

Overall, the catalysts used converted the entire amount of NH_3BH_3 at a relatively low temperature, confirmed by ^{10}B-NMR spectroscopy. Furthermore we analyzed the results using the Design Expert software and, based on the previously defined experimental design, we selected the optimal catalyst and reaction conditions for further measurements.

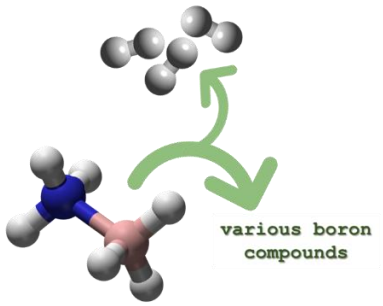

Figure 1. H_2-evaluation from NH_3BH_3

Acknowledgment

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References

1 G. Papp, G. Ölveti, H. Horváth, Á. Kathó and F. Joó *Dalton Trans*., **2016**, *45*, 14516-14519

2 G. Papp, J. Csorba, G. Laurenczy, and F. Joó *Angew. Chem. Int. Ed*. **2011**, *50*, 10433-10435

3 A.V. Bulatov, E. N. Izakovich, L. N. Karklin', and M. L. Khidekel, *Bulletin of the Academy of Sciences of the USSR*, **1982,** *30 (9),* 1667-

Development of aerogel-based sorbents for the selective recovery of noble metal ions and investigation of their binding mechanisms

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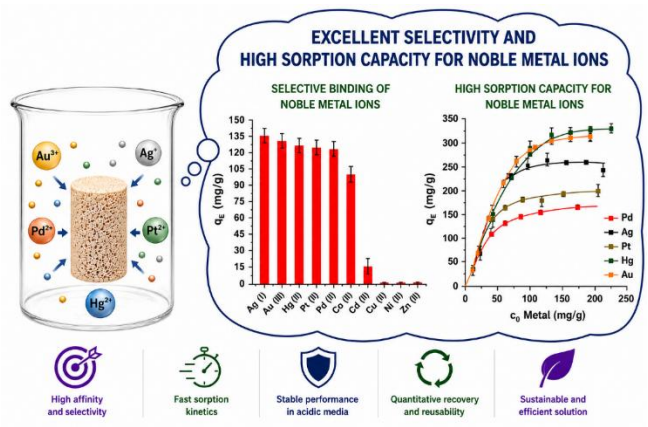
The increasing industrial demand for noble metals, together with their limited natural resources, has intensified the need for efficient recovery strategies. Conventionally, noble metals are leached in acidic media and subsequently recovered from the resulting solutions using solvent extraction, sorption, or ion-exchange techniques. Among these approaches, sorption has emerged as a particularly attractive alternative owing to its high efficiency, cost-effectiveness, and the possibility of tailoring sorbent properties for selective metal-ion uptake.[1] Aerogels represent a versatile class of sorbent materials due to their highly porous architecture, large specific surface area, and broad opportunities for chemical functionalization. These characteristics make them especially suitable for the selective adsorption of hydrated noble metal ions from aqueous solutions.[2] This contribution presents the preparation of porous aerogel sorbents synthesized from different precursor systems via sol–gel processing.[3] The structural, morphological, and chemical properties of the obtained materials were investigated by low-voltage scanning electron microscopy (LV-SEM), nitrogen adsorption porosimetry, Fourier-transform infrared (FT-IR), Raman, X-ray photoelectron (XPS), and solid-state NMR spectroscopy. Their sorption behaviour was evaluated by equilibrium and kinetic experiments performed in stirred reactor systems, while the concentrations of dissolved metal ions were quantified by inductively coupled plasma (ICP) analysis. The synthesized aerogels exhibited high affinity toward hydrated noble metal ions and reached sorption equilibrium within a relatively short time. Furthermore, the adsorbed metal ions were quantitatively recovered using solutions containing low-molecular-weight ligands. The mechanisms governing metal-ion binding on the aerogel surface were elucidated using complementary spectroscopic techniques.



Acknowledgment

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References

[1] Nakhjiri, A. T.; Sanaeepur, H.; Amooghin, A. E.; Shirazi, M. M. A. *Desalination* **2022**, *527*, 115510.

[2] Herman, P.; Pércsi, D.; Fodor, T.; Juhász, L.; Dudás, Z.; Horváth, Z. E.; Ryukhtin, V. A.; Putz, M. A.; Kalmár, J.; Almásy, L. *J. Mol. Liq.* **2023**, *387*, 122598.

[3] Pércsi, D.; Forgács, A.; Fodor, T.; Fábián, I.; Kalmár, J.; Herman, P. *ACS Appl. Nano Mater.* **2024**, *7* (12), 14629–14640.

Copper(II) complexes of pyridine-based macrocycles with antioxidant activity

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Superoxide dismutase (SOD) enzymes catalyze the decomposition of superoxide anion ($O_2^{\bullet-}$), generated during the aerobic metabolism of molecular oxygen, to hydrogen peroxide and oxygen.[1] The absence of SOD enzyme or increased reactive oxygen species (ROS) levels may induce oxidative stress, which can damage proteins, DNA chains, cell membrane, and promote the development of cancerous cells.[2] In this work, we synthetised new macrocyclic SOD mimetics using the previously studied PydiHis ligand containing pyridine-2,6-dicarboxamide backbone.[3] The two macrocycles were prepared using either a pyridine ring (PydiHisPy) or a butyl chain (PydiHisBut) as bridging group (Figure 1.). The complex formation reaction between copper(II) and the ligands were studied by pH potentiometry and spectroscopic (UV-Vis, MS, CD, and EPR) methods. Based on the calculated conditional stability constants for the Cu(II)-PydiHis, Cu(II)-PydiHisPy, and Cu(II)-PydiHisBut complexes at physiological pH, the macrocyclic complexes possess lower stability compared to its open-chained derivative. The SOD activity of the copper(II) complexes was determined at physiological pH using xanthin/xanthin oxidase/NBT assay (McCord-Fridovich assay) and sequential stopped-flow method. Although the macrocyclic systems have lower stability, they show one order of magnitude higher SOD activity.

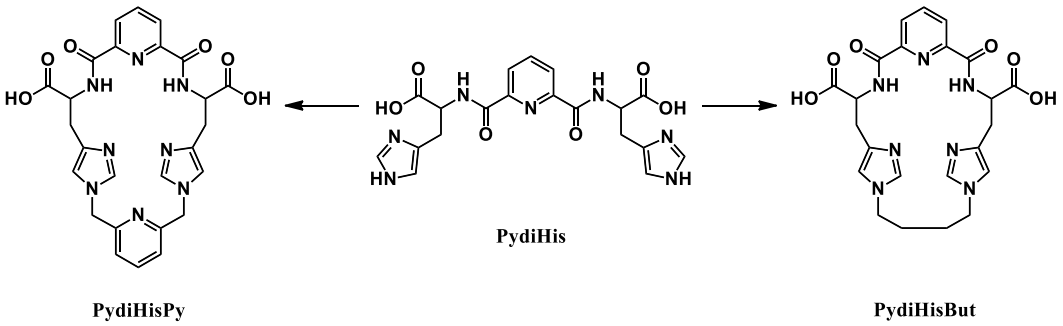

Figure 1. Structure formulae of PydiHisPy and PydiHisBut ligands.

Acknowledgment The authors are grateful for the financial support of the Hungarian National Research, Development and Innovation Office (STARTING25 152343). This work was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences and the University of Debrecen Scientific Research Bridging Fund (DETKA).

References

[1] Molonev, J. N.; Cotter, T. G., *Semin. Cell Biol.* **2018**, *80*, 50-64.

[2] Sheng, Y.; Abreu, I. A.; Cabelli, D. E.; Maroney, M. J.; Miller, A.-F.; Teixeira, M.; Valentine, J. S., *Chem. Rev.* **2014**, *114* (7), 3854-3918.

[3] Diószegi, R.; Guidetti, A.; Ág, N.; Serra, I.; Szalóki, D.; Bonczidai-Kelemen, D.; May, N. V.; Fekete, E.; Karaffa, L.; Fábián, I.; Van Doorslaer, S.; Lihi, N., *Inorg. Chem. Front.* **2025**, *12* (24), 8690-8705.

Coordination of azoderivatives to the $\{Pt^{II}(TMEDA)\}^{2+}$ fragment; robustness of the *E*↔*Z* photothermal py-Ph ligand isomerisation and striking influence of the solvent in the *Z*→*E* thermal process

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E↔*Z* photothermal ligand isomerisation of azoderivatives is currently a subject of high importance. This results specially interesting when dealing with robust photoswitches, where the thermal back isomerisation *Z*→*E* that can be modulated through coordination to metal centres. The tuning of azoderivatives in a way that, while avoiding the push-pull effect, produces relatively fast controlled thermal *Z*→*E* isomerisation in aqueous medium.

In this respect, water-soluble complexes [Pt(**py-Ph**)(TMEDA)(solvent)]$^{2+}$ and [Pt(**py-Ph**)$_2$(TMEDA)]$^{2+}$ (Figure 1) have been prepared from the [Pt(CH$_3$CN)$_2$(TMEDA)]$^{2+}$ precursor *via* neat substitution procedures. The compounds have been fully characterised by NMR spectroscopy and HRMS ESI spectrometry; in all cases these complexes show a definite robustness and stability, which their Pd^{II} analogues lack.

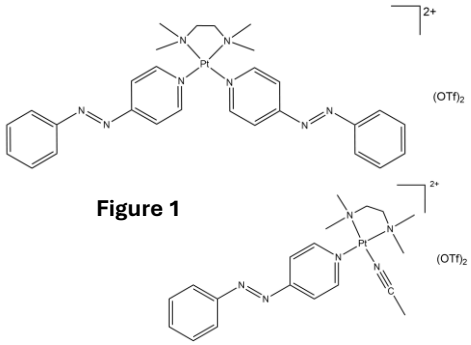


Figure 1

The phothermal *E*→*Z*→*E* isomerisation reaction of the azoderivatives in these complexes has been studied in different solvents and varying temperatures and pressures (Figure 2). As observed in previously studied systems, the results indicate a change in the isomerisation mechanism from rotational (charge separation) to inversional (-N=N- maintenance) on coordination to the metal centre.[1] This is surprising, given the fact that an important decrease of the rate constant is observed on going from acetonitrile to water. Furthermore, as found also in previous studies, no cooperativity between the isomerization of the two azo ligands is observed,[2, 3] as the rates of the processes occurring in [Pt(TMEDA)(**py-Ph**)(solvent)]$^{2+}$ and [Pt(TMEDA)(**py-Ph**)$_2$]$^{2+}$ compounds are equivalent.

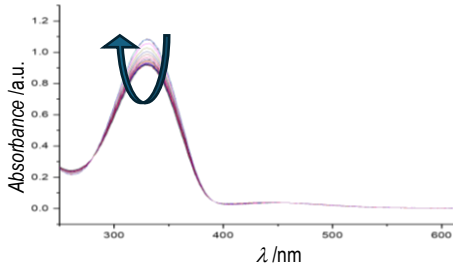
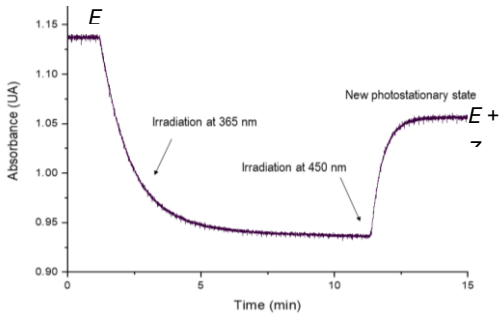


Figure 2



Acknowledgment: Financial support from project PID2024-159753OB-I00 (Ministerio de Ciencia, Innovación y Universidades) is acknowledged.

References

1 Martínez, M.; Ferrer, M.; Garcia-Cirera, B.; Gallen, A.; Font-Bardia, M.; Bardaji, M. *Dalton Trans*. **2023,** *52*, 1720.

2 Raïch Panisello, O.; Jover, J.; Puigjaner, C.; Ferrer, M.; Martínez, M. *Inorg. Chem*. **2024,** *63*, 16251.

3 Raïch Panisello, O.; Jover, J.; Puigjaner, C.; Ferrer, M.; Martínez, M. *Dalton Trans*. **2025,** *54* , 15134.

Interaction of Aqueous Bovine Serum Albumin with Silica Aerogel Microparticles: Sorption Induced Aggregation

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Understanding the nature of biomolecule interactions with highly porous, nanostructured materials is fundamental for advancing applications in biotechnology, pharmacy, and medicine.[1, 2] To model protein-aerogel interactions in the solution phase, this study investigated the reaction kinetics and binding mechanisms of aqueous bovine serum albumin (BSA) with mesoporous silica aerogel microparticles. The interaction within this colloid system was monitored on-line utilizing time-resolved UV-vis spectrophotometry and turbidimetry immediately following the injection of the dissolved protein into the aerogel suspension.

Mathematical analysis of the kinetic data reveals that the interaction deviates from classical single-step equilibrium models, such as Langmuir or Temkin, and instead follows a two-stage, reversible kinetic mechanism. Initially, BSA rapidly adsorbs onto bare aerogel particles to form protein-covered particles, a process defined by adsorption (k_1) and desorption (k_2) rate constants. Subsequently, the multilayer sorption of additional BSA fundamentally alters the silica aerogel's electrical double layer. This secondary binding neutralizes the stabilizing Coulomb repulsion between natively negatively charged particles, directly inducing macroscopic aggregation governed by aggregation (k_3) and disaggregation (k_4) constants. This pathway's rate and extent depend heavily on pH, maximizing between pH 4 and 5. At pH 4.6 in an acetate buffer, BSA is near its isoelectric point and carries a positive surface charge, while the aerogel remains negatively charged. This electrostatic attraction creates a densely packed protein film, yielding covered particles with a near-zero net charge. This neutralized state minimizes protein-protein repulsion, facilitating rapid aggregation. Elucidating this multistep aggregation pathway offers critical insights for evaluating and optimizing mesoporous silica in biomaterial applications.

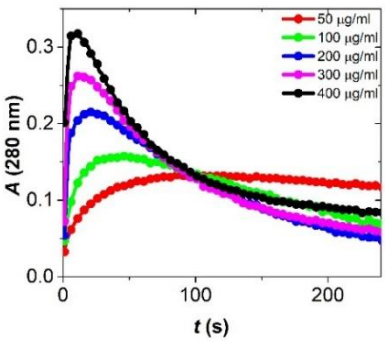

Figure 1. Kinetic curves of BSA adsorption in acetate buffer pH = 4.6.

References

1. García-González, C. A.; Sosnik, A.; Kalmár, J.; De Marco, I.; Erkey, C.; Concheiro, A.; Alvarez-Lorenzo, C., Aerogels in drug delivery: From design to application. *Journal of Controlled Release* **2021,** *332*, 40-63.
2. Király, G.; Egu, J. C.; Hargitai, Z.; Kovács, I.; Fábián, I.; Kalmár, J.; Szemán-Nagy, G., Mesoporous aerogel microparticles injected into the abdominal cavity of mice accumulate in parathymic lymph nodes. *International Journal of Molecular Sciences* **2021,** *22* (18), 9756.

Effect of fluoride ions on homogeneous catalytic CO_2 hydrogenation

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Environmental pollution, particularly air pollution, is one of the major challenges of our time. The use of alternative energy carriers is becoming increasingly important, with hydrogen being one of the most promising candidates due to its high gravimetric energy density and its applicability in fuel cells. However, the safe and economical storage and transportation of H_2 remain unresolved challenges.

Our research group focuses on homogeneous catalytic hydrogen storage in aqueous media, with formic acid (HCOOH) serving as one of the key hydrogen carriers. In previous studies, we successfully developed and investigated efficient hydrogen storage systems based on water-soluble transition-metal catalysts (Ir, Ru, and Rh).

The present work builds on earlier investigations of the effect of halide ions on the decomposition of HCOOH catalyzed by the *cis,mer*-[IrH_2Cl(*m*tppms-Na)$_3$] complex. These experiments, performed using an atmospheric-pressure gas burette, demonstrated that the presence of fluoride ions enhances the reaction rate. Density functional theory (DFT) calculations revealed that HF is formed during the reaction and acts as a co-catalyst, promoting H_2 evolution.

In this work, we investigated the hydrogenation of CO_2 catalyzed by the *cis,mer*-[IrH_2Cl(*m*tppms-Na)$_3$] complex in the presence of fluoride ions. A significant positive effect of fluoride ions on the hydrogenation reaction was observed over a wide range of NaF concentrations and under various temperature and pressure conditions.

Our results demonstrate that fluoride ions act as co-catalysts in the investigated catalytic system. Consequently, they promote both steps of the formic acid-based hydrogen storage cycle, namely the reduction of CO_2 and the decomposition of formic acid.

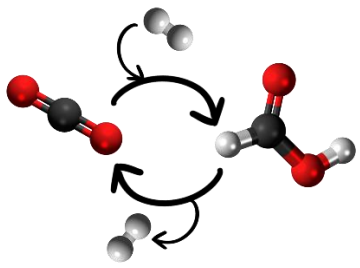

Figure 1. H_2-storage cycle in HCOOH/CO_2

Acknowledgment

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References

a) Papp, G.; Ölveti, G.; Horváth H.; Kathó Á.; Joó F., *Dalton Trans.*, **2016**, *45*, 14516

b) Papp G.; Csorba J.; Laurenczy G.; Joó F., *Angew. Chem. Int. Ed.* **2011**, *50*, 10433

The formation of chloroacetic acid during the chlorination of aspartic acid

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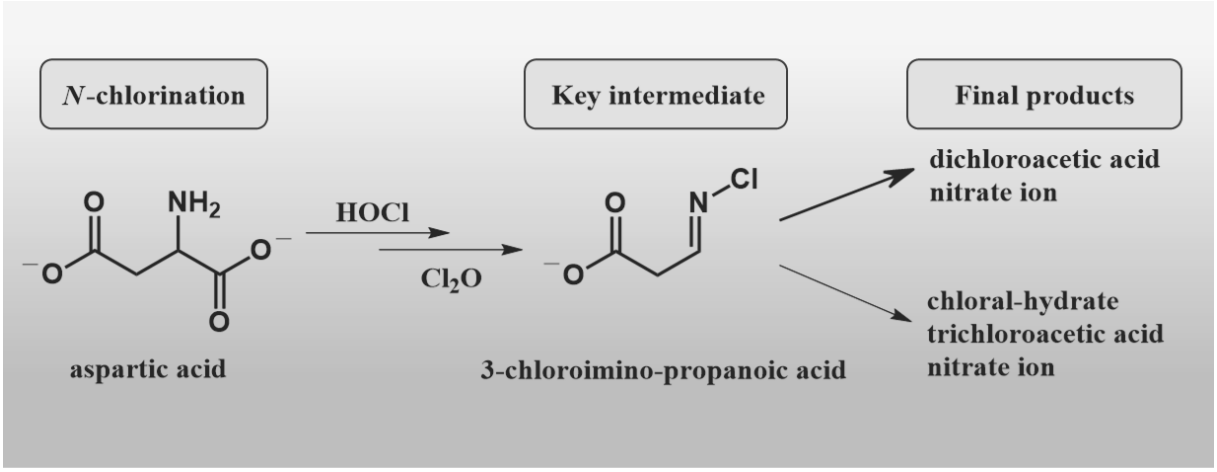
Chlorination is the most widely applied disinfection method in drinking water treatment, but it may lead to the formation of harmful disinfection by-products (DBPs).[1] Amino acids present in natural waters and algal biomass are regarded as important precursors of DBPs.[2] In this study, the chlorination of aspartic acid (Asp), one of the most abundant amino acids in natural waters, was investigated to elucidate the kinetics and mechanism of haloacetic acid formation. Stopped-flow spectrophotometry revealed that the reaction begins with the rapid formation of N-chloroaspartic acid, followed by chlorination to N,N-dichloroaspartic acid. Kinetic analysis shows that the second chlorination step involves dichlorine monoxide (Cl_2O), which is an effective chlorinating agent under neutral conditions. The dichloro derivative subsequently decomposes in a first-order process forming a relatively stable intermediate, 3-chloroimino-propanoic acid (CIPA). Time-resolved ^{1}H NMR spectroscopy and ion chromatography demonstrated that this intermediate transforms into the final products through multiple reaction paths over several hours. The dominant pathway involves the formation of cyanoacetic acid (CNAA), which is oxidized to dichloroacetonitrile (DCACN) and ultimately to dichloroacetic acid (DCAA) which is the main product of the reaction. The minor pathway leads to the formation of chloral hydrate (ChH) and subsequently trichloroacetic acid (TCAA). Nitrate ion is the major nitrogen-containing final product. The proposed kinetic model consistently explains all experimental observations and provides new insight into the formation of haloacetic acids from amino acids during water chlorination.



Acknowledgment

This study was supported by the EKÖP-24-3 and EKÖP-24-4 University Research Scholarship Program of the Ministry for Culture and Innovation from the source of the National Research, Development and Innovation Found of Hungary and also by a research grant, OTKA-139140.

References

1. Stalter, D.; O'Malley, E.; von Gunten, U.; Escher, B. I., Fingerprinting the reactive toxicity pathways of 50 drinking water disinfection by-products. *Water Research* **2016,** *91*, 19-30.
2. Wu, Y. T.; Luo, X. F.; Li, G. C.; Zhou, S. Q., Effect of chlorine dioxide pre-oxidation on algal non-protein amino acid degradation and DBPs formation during subsequent chlor(am)ination. *Process Safety and Environmental Protection* **2022,** *164*, 30-37.

An old-new ligand family for complexation of Cu(II) in radiotheranostics

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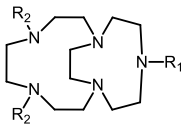
Based on the results published in the last years, the radiolabelled prostate-specific membrane antigen (PSMA) has been deemed suitable for the detection of prostate cancer, while the NAPamide molecule can be used in the non-invasive detection of melanin producing melanoma tumors.[1]

There is growing interest in the combined application of targeted diagnosis and therapy for the personalized and precise medicine. One of the most promising candidates for this purpose is the ^{64}Cu isotope thanks to its excellent decay properties.[2] Of course, for the successful applications, the in vivo degradation of the ^{64}Cu agents must be avoided by means of highly inert complexes (usually conjugated with biomolecules),[3] however the formation of the complexes with frequently used chelates is very slow.[4]

Therefore, it is easy to see that developments of ligands show fast complexation with Cu(II) is highly desired. For this reason, we have synthesized and studied the Cu(II) complexes of 1,4,7,10,13-pentaazabicyclo{8.5.2}heptadecane (CB-15aneN$_5$) ligand and its derivatives. The synthesis of the cross-bridged parent macrocycle (Figure 1.), has been described almost two decades ago, however detailed investigation were not carried out.[5]



CB-15aneN$_5$: R_1 = H, R_2 = H
*p*NO$_2$Bn-CB-15aneN$_5$: R_1 = *p*-nitrobenzyl, R_2 = H
KFTG: R_1 = *p*-benzoic acid, R_2 = H
KFTGdiac: R_1 = *p*-benzoic acid, R_2 = OAc

Figure 1. The structure of the ligands.

The results of our investigations shows that the ligands, CB-15aneN$_5$, *p*NO$_2$Bn-CB-15aneN$_5$, KFTG, KFTGdiac possess fast complexation with Cu(II) at 25 °C and pH=5 ($t_{1/2}$≈2.5 min), furthermore the thermodynamic stability of the Cu(II) chelates is very high (log$K$[$_{Cu(CB\text{-}15aneN5)}$]=28.3) keeping the Cu(II) ion in complexed form above pH = 2. The dissociation half-lives of the above mentioned chelates were found to be 0.13, 2.3, 2.0 and 0.5 hours in the presence of 5.0 M HCl at 50 °C, respectively, providing very high inertness at physiological pH. Furthermore, the radiolabeling experiments of the ligands with ^{61}Cu(II) isotope indicated that the labeling is complete in the μM range at pH = 6.0 and room temperature in a short period of time. The *in vitro* and *in vivo* experiments performed by using PSMA and NAPamide target molecules indicated excellent diagnostic potential for the [Cu(KFTG)]$^+$- and [Cu(KFTGdiac)]-based radiopharmacons. In addition, a series of investigations concerning the potential therapeutic applications of the (^{64}Cu)[Cu(KFTG)]-NAPamid in melanoma tumours is currently in progress. Based on these findings it can be concluded that this ligand family provide promising platforms for Cu(II) complexation in radiodiagnostics and radiotherapy.

Acknowledgment

This work was supported by the University of Debrecen Scientific Research Bridging Fund (DETKA)

References

[1] Nagy, G., et al., *Eur. J. Pharm. Sci.* **2017**, *106*, 336-344
[2] Calabria, F.; Schillaci, O., Radiopharmaceuticals, Springer: Cham, **2019**;
[3] Anderson, C.J., et al., *Cancer Biother. Radiopharm.* **2009**, *24(4)*, 379–393
[4] Lima, L.M.P., et al., *Inorg. Chem.* **2014**, *53(10)*, 5269-5279
[5] Shircliff, A.D., et al., *Chem. Commun.* **2020**, *56*, 7519–7522

Vitamin loaded PVA electrospun nanofibers

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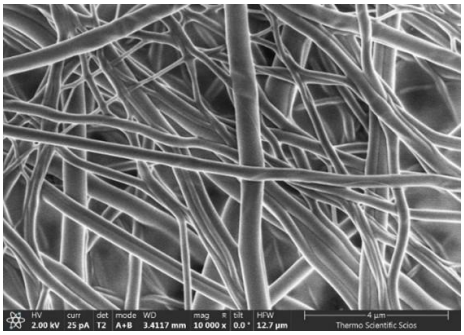
Electrospun nanofibers have attracted considerable attention as advanced wound dressing systems due to their structural similarity to the extracellular matrix, high surface area, porosity, and ability to incorporate biologically active compounds. In this study, poly(vinyl alcohol) (PVA)-based electrospun nanofibrous mats containing panthenol (provitamin B5) and *α*-tocopherol (vitamin E) were developed as multifunctional wound-healing materials.[1] The simultaneous incorporation of hydrophilic and lipophilic bioactive molecules into a single polymeric system presents a considerable formulation challenge because of their different solubility characteristics.
The influence of vitamin concentration, formulation strategy, and sodium dodecyl sulfate (SDS) as a surfactant on fiber morphology, vitamin incorporation, and thermal properties was systematically investigated. Fiber morphology was characterized by low-voltage scanning electron microscopy, while vitamin incorporation and release were analyzed using high-performance liquid chromatography for vitamin E and gas chromatography - mass spectrometry for panthenol. Thermal stability and degradation behavior were examined by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA). SEM observations revealed that increasing vitamin E concentration significantly affected fiber morphology, leading to partial fiber fusion and an increase in average fiber diameter from approximately 220 nm to 400 nm, likely reflecting the lipophilic nature of *α*-tocopherol and its limited compatibility with the hydrophilic PVA matrix. In contrast, panthenol had little influence on fiber morphology or diameter distribution. Simultaneous incorporation of both vitamins was successfully achieved without major deterioration of fiber integrity.
Overall, the developed electrospinning strategy enables the successful incorporation of both hydrophilic and lipophilic vitamins into PVA nanofibers while maintaining favorable structural characteristics. These findings demonstrate the feasibility of co-encapsulating hydrophilic and lipophilic bioactive compounds into electrospun PVA nanofibers and provide a foundation for the development of multifunctional wound-healing scaffolds.



SEM micrographs of electrospun PVA nanofibers containing panthenol (vitamin B5) and α-tocopherol (vitamin E).

Acknowledgment This study was supported by the Ministry for Culture and Innovation Office as follows: Hungarian Science Foundation grant (under grant number OTKA-139140) and Project C1775385 under the KDP-2021 funding scheme. We highly appreciate the financial support provided by Premed Pharma Ltd (Hungary).

References

[1] Boateng, J. S.; Matthews, K. H.; Stevens, H. N. E.; Eccleston, G. M., *J. Pharm. Sci.* **2008**, 97 (8), 2892-2923

Attachment of py-Ph azoderivatives to the $\{Ru^{II}cis\text{-}(bpy)_2\}^{2+}$ skeleton; coexistence of the photothermal *cis*↔*trans* skeleton and *E*↔*Z* ligand isomerisation reversible reactions

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The importance of the *E*↔*Z* photothermal ligand isomerisation of azoderivatives is a subject of high interest.[1] This is particularly relevant when dealing with robust photoswitches where the thermal back isomerisation *Z*→*E* that can be modulated via solvent choice and coordination to metal centres. The attachment of these units to the biologically relevant $\{Ru^{II}cis\text{-}(bpy)_2\}^{2+}$ skeleton is of key importance, as it can affect the luminescence of the complex, as well as its capability to intercalate in the DNA chain.[2] Nevertheless, the fact that the complex with this skeleton and monodentate ligands shows definite *cis-trans* isomerisation, normally including photochemical ligand ejection, limits its use.[3]

In this line, we have prepared the water-soluble complex *cis*-$[Ru(bpy)_2(\mathbf{py\text{-}Ph})_2]^{2+}$ (Figure 1) from the corresponding diaqua precursor *via* neat substitution procedures. The compound has been fully characterised and shows a definite robustness and stability which its monosubstituted *cis*-$[Ru(bpy)_2(\mathbf{py\text{-}Ph})(H_2O)]^{2+}$ equivalent lacks. The compound undergoes two reversible isomerisation reactions that include the *cis/trans* arrangement of the ruthenium skeleton and the *E/Z* form of the two azoderivatives.

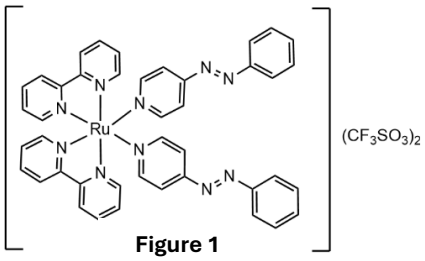


Figure 1

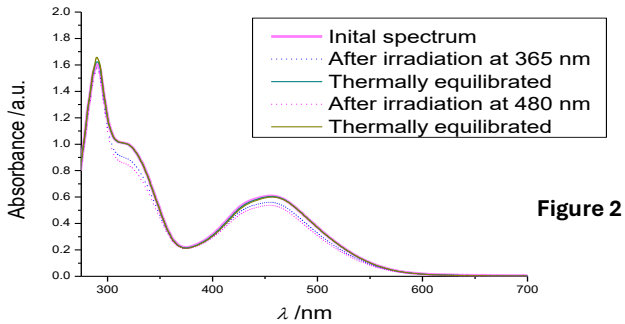
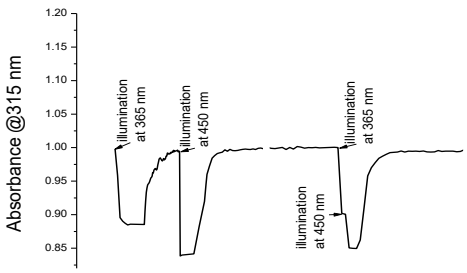


Figure 2



The photothermal isomerisation reactions have been studied at different illumination wavelengths (involving the *cis/trans* arrangement and the *E/Z* form of the two azoderivatives) and found to be practically independent (Figure 2). In all cases the prevalence of the starting compound has been determined by the intensity of the UV-Vis spectral signals and the monitoring of the ^{1}H NMR of the samples.

Acknowledgment: Financial support from project PID2024-159753OB-I00 (Ministerio de Ciencia, Innovación y Universidades) is acknowledged.

References

1 Garcia-Amoros, J.; Stopa, G.; Stochel, G.; van Eldik, R.; Martinez, M.; Velasco, D. *Phys. Chem. Chem. Phys.* **2018,** *20*, 1286-1292.
2 de Souza Arantes, E. C.; Bessas, N. C.; de Oliveira Sanches, R. L.; dos Santos, A. L. R.; de Sousa Amorim, L.; Nunes, V. S. P.; Cassani, N. M.; Ruiz, U. H. A.; Martin, M. T.; Llontop, C. A. P.; de Faria, A. M.; Graminha, A. E.; DeFreitas-Silva, G.; Jardim, A. C. G.; Sgro, G. G.; da Silva Paschoal, D. F.; de Lima, R. G. *J. Inorg. Biochem.* **2026,** *280*, 113291.
3 Rojas Perez, Y.; Slep, L. D.; Etchenique, R. Complexes. *Inorg. Chem.* **2019,** *58*, 11606-11613.

Homogeneous Hydrogenation of CO_2/HCO_3^- in Aqueous Media Using the *cis,mer*-[IrH_2Cl(*m*tppms-Na)$_3$] Catalyst

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Molecular hydrogen is considered a promising energy carrier; however, its widespread application is limited by the lack of safe and energy-efficient storage methods. Although several hydrogen storage technologies have been developed, they generally involve either significant safety risks (compressed hydrogen storage) or high energy penalties (cryogenic liquid hydrogen storage). One of the most attractive alternatives is chemical hydrogen storage, in which hydrogen is stored in the chemical bonds of suitable compounds. Among chemical hydrogen storage materials, formic acid represents one of the most promising candidates.

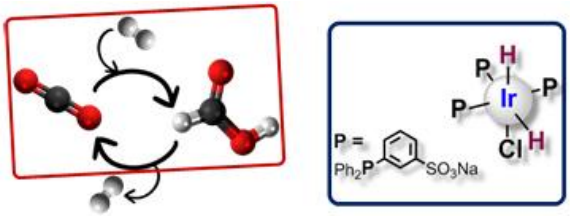

Figure 1. CO_2/HCOOH hydrogen storage system and the structure of the *cis,mer*-[IrH_2Cl(*m*tppms-Na)$_3$] complex.

Our research group reported the synthesis of the *cis,mer*-[IrH_2Cl(*m*tppms-Na)$_3$] complex approximately 10 years ago, along with its outstanding catalytic activity for hydrogen evolution from formic acid.[1] According to the literature, it ranks among the three most active catalysts reported for this reaction (**Figure 1**).

In this presentation, we report our recent results on the catalytic hydrogenation of the CO_2/HCO_3^- system in a closed, stirred batch reactor under relatively mild reaction conditions. We demonstrate that the *cis,mer*-[IrH_2Cl(*m*tppms-Na)$_3$] complex, which exhibits excellent catalytic activity in H_2 evolution from formic acid, is also highly active in the reverse process, namely the hydrogenation of CO_2/bicarbonate to formate.

Acknowledgment: This work was supported by the RRF-2.3.1-21-2022-00009 project, *National Laboratory for Renewable Energy*, funded by the European Union under the Széchenyi Plan Plus through the Recovery and Resilience Facility (RRF).

References

[1] Papp, G.; Ölveti, G.; Horváth H.; Kathó Á.; Joó F., *Dalton Trans.*, **2016**, *45*, 14516

Catechol oxidase activity of a dinuclear copper(II) complex

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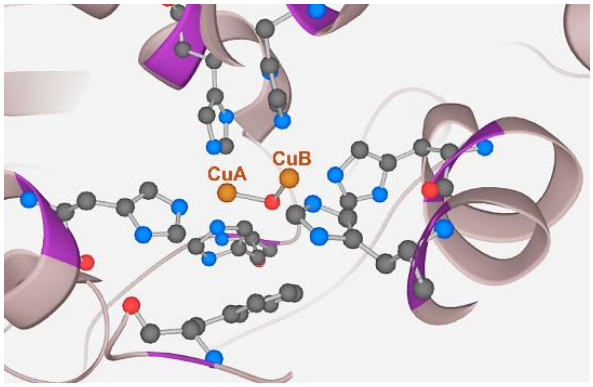
Enzymes with metal-centered active sites serve as key inspirations for designing selective and efficient biomimetic complexes. Among these, Type 3 copper proteins—such as hemocyanin, tyrosinase, and catechol oxidase—possess magnetically coupled dinuclear copper(II) centers capable of activating molecular oxygen.[1] Catechol oxidase specifically catalyzes the oxidation of catechol-type substrates into biologically and industrially relevant quinone derivatives. Developing such biomimetic catalytic systems provides a green chemistry alternative to classical stoichiometric oxidation methods, which rely on toxic reagents. However, utilizing O_2 poses significant challenges due to its kinetic inertness and the difficulty of controlling its reactivity to prevent over-oxidation and low selectivity.[2-5]



Scheme 1. The structure of the catechol oxidase active site.

In this work, a novel copper(II) complex was designed and synthesized as a structural and functional model for catechol oxidase. The newly prepared ligand incorporates multiple pyridine subunits capable of simultaneously coordinating at least two metal centers. Complexation reactions with copper(II) ions were thoroughly investigated, establishing stability constants and key spectroscopic parameters. Furthermore, the catalytic reactivity of the resulting complex was evaluated at physiological pH using ortho-dihydroxybenzene (ortho-catechol) derivatives as structural analogs of natural substrates, demonstrating its potential as an efficient biomimetic catalyst.

Acknowledgment The authors are grateful for the financial support of the Hungarian National Research, Development and Innovation Office (OTKA STARTING25-152343).

References

[1] Dey S. K.; Mukherjee A., *Coord. Chem. Rev.* **2015**, *310*, 80-115.

[2] Torelli S., Belle C., Hamman S., Pierre J. L., Saint-Aman E., Inorg. Chem. **2002**, *41* (15) 3983-9.

[3] Eicken C.; Krebs B.; Sacchettini J. C., *Curr. Opin. Struct. Biol.* **1999**, *9* (6) 677-83.

[4] Massey V., *J. Biol. Chem.* **1994** *269*, 22459–22462.

[5] Bugg T. D. H., *Tetrahedron* **2003**, *59*,7075–7101.

[6] Thierbach S.; Bui N.; Zapp J.; Chhabra S.R.; Kappl R.; Fetzner S., *Chem. Biol.*, **2014**, *21* (2), 217-225.

Structure–Property Relationships in Acyclic Lanthanide Chelators

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Radiolanthanum is versatile candidate to the radiopharmaceutical application owing to the diverse decay characteritics of its isotopes, which enable both diagnostic (^{132}La, ^{133}La) and therapeutic (^{135}La) applications.[1] La^{3+} possesses the largest ionic radius is among the lanthanide ions, which in some cases results in the formation of ten-or even eleven coordinate complexes.[2] Moreover, the slow formation kinetics of the macrocyclic chelators such as DOTA, limit their application in radiochemistry. The rigid acyclic *CHX*OCTAPA chelator was found to be more promising candidate than the flexible OCTAPA owing to the remarkably high inertness of its metal complexes.[3] In this study we successfully synthesized two acyclic decadentate chelators (Figure 1.) and investigated the thermodynamic, kinetic and radiochemical properties of their La^{3+} complexes. The protonation constants determined by pH-potentiometric titration correlated well with the electron-withdrawing effect of the picolinate pendant arms and the inductive effect of the cyclohexyl unit. These effects are reflected in the *log* K_1^H and *log* K_2^H values, which correspond to the protonation of the secondary amine nitrogen atoms in the ligand backbone. The stability constants (*log* K_{LaL}) of the La^{3+} complexes are comparable to those reported for the analouges acyclic and macrocycles compounds (*log* $K_{LaTPAEN}$ = 19.16(8) and *log* $K_{LaTPADAC}$ = 19.55(1)). The Cu^{2+}-mediated dissociation kinetics of the $[La(TPAEN)]^-$ and $[La(TPADAC)]^-$ complexes were investigated over a wide pH-range at various scavenger concentrations. The dissociation kinetic studies revealed both first-order (k_1) and quatradic (k_2) dependence on the proton concentrations, while a metal-assisted (k_3) pathway was also evidenced. At higher pH values the the formation of dinuclear hydroxo-species (k_6) accelerated the dissociation of the La^{3+}-complexes. Quantitative radiolabeling of both chelators with $[^{135}La]La^{3+}$ was achieved at pH~4−5 using low ligand concentrations. Both *in vitro* and *in vivo* studies indicate that the $[^{135}La]La(TPAEN)^-$ exhibits significantly higher stability than the TPADAC analogue, highlighting the potential of the TPAEN scaffold for future radiolathanum-based radiopharmaceutical applications.

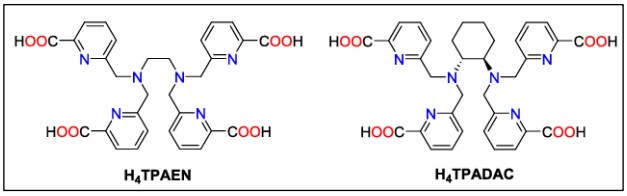

Figure 1. The structures of the discussed decadentate ligands.

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References

[1] Nelson, B. J. B., Andersson, J. D., Wuest, F. *Nucl. Med. Biol*. **2022**, *110–111*, 59–66.

[2] Thiele, N. A., Brown, V., Kelly, J.M., Amor-Coarasa, A., Jermilova, U., MacMillan, S. N., Nikolopoulou, A., Ponnala, S., Ramogida, C. F., Robertson, A. K. H., Rodríguez-Rodríguez, C., Schaffer,P., Williams,C., Babich, J.W., Radchenko,V., Wilson, J. J., *Angew. Chem., Int. Ed*. **2017**, *56 (46),* 14712−14717.

[3] Ramogida, C. F., Cawthray, J. F., Boros, E., Ferreira, C. L., Patrick, B. O., Adam, M. J., Orvig, C. *Inorg.Chem*. **2015**, *54(4)*, 2017−2031.

Water-Soluble Ru(II)–PTA Catalysts for Reversible Hydrogen Storage Applications

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Global energy demand continues to increase and is still predominantly met by the combustion of fossil fuels. The growing contribution of renewable energy sources has led to an increasing demand for efficient and safe energy storage technologies, with hydrogen regarded as one of the most promising energy carriers.

However, the storage and transportation of hydrogen gas remain significant technological challenges. Therefore, liquid hydrogen carriers, such as formic acid and its salts (formates), bicarbonate, and ammonia–borane, have attracted considerable attention because hydrogen can be catalytically released at the point of use. At the same time, the resulting products can be hydrogenated back to the corresponding hydrogen carriers.

At the Homogeneous Catalysis Research Group of the University of Debrecen, particular attention is devoted to ruthenium(II) complexes containing the water-soluble ligand 1,3,5-triaza-7-phosphaadamantane (PTA) and its cationic derivatives. Compared with conventional sulfonated triphenylphosphine ligands, PTA exhibits excellent stability toward air oxidation, even in alkaline aqueous media, making it an attractive ligand for the development of robust and sustainable catalytic systems[1].

In the present work, various Ru(II)–PTA catalyst systems [$RuCl_2(DMSO)_4$ + 3P] have been investigated for aqueous hydrogen storage applications. The dehydrogenation of ammonia–borane was studied using in situ generated catalyst systems. Furthermore, the catalytic activity of the coordinatively unsaturated *trans,mer*-[$RuCl_2(H_2O)(PTA)_3$][2] was investigated in the dehydrogenation of formic acid and sodium formate, as well as in the catalytic hydrogenation of bicarbonate to formate under hydrogen pressure in a Parr reactor®, representing a key step in the reversible hydrogen storage cycle. The effects of reaction temperature and pH were systematically investigated.

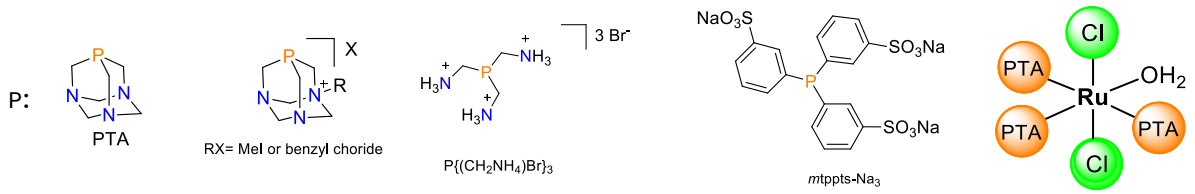

Figure 1: Phosha-urotropines, *m*tppts-Na_3 and *trans,mer*-[$RuCl_2(H_2O)(PTA)_3$]

These results demonstrate that Ru(II)–PTA catalyst systems efficiently promote both hydrogen release and hydrogen uptake in aqueous media, highlighting their potential as versatile catalysts for the development of reversible hydrogen storage technologies. These results demonstrate that Ru(II)–PTA catalyst systems efficiently promote both hydrogen release and hydrogen uptake in aqueous media, highlighting their potential as versatile catalysts for reversible hydrogen storage technologies.

Acknowledgment

The authors are grateful for Financial support from project no. RRF-2.3.1-21-2022-00009, titled National Laboratory for Renewable Energy, has been provided by the Recovery and Resilience Facility of the European Union within the framework of Programme Széchenyi Plan Plus, which is gratefully acknowledged. A.U. is grateful for the general support of János Bolyai Research Scholarship.

References

[1] a) Phillips, A.D.; Gonsalvi, L.; Romerosa, A.; Vizzaa, F.; Peruzzini, M. *Coord. Chem. Rev.* **2004**, *248*, 955-993. b) Bravo, J.; Bolano, S.; Gonsalvi, L.; Peruzzini, M. *Coord. Chem. Rev.* **2010**, 254, 555-607; c) Guerriero, A.; Peruzzini, M.; Gonsalvi, L., *Coord. Chem. Rev.* **2018**, *355*, 328-361 d) Udvardy, A., Joó, F., Kathó, Á., *Coord. Chem. Rev.* **2021**, 438, 213871

[2] Udvardy, A.; Serrano-Ruiz, M.; Passarelli, V.; Bolyog-Nagy, E.; Joó, F.; Kathó, Á.; Romerosa, A. *Inorg. Chim. Acta.* **2018**, *470*, 82-92

Copper(II) complexes of histidine-based benzo-fused heterocyclic ligands: equilibrium and kinetic features

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Superoxide dismutases (SODs) are essential components of the cellular antioxidant defense system, catalysing the disproportionation of the superoxide anion radical, one of the major reactive oxygen species (ROS) generated in biological systems[1]. Disturbances in ROS regulation may lead to oxidative stress, which has been associated with numerous pathological conditions[2]. Consequently, the development of low-molecular-weight systems capable of regulating ROS levels has attracted considerable interest.
A series of histidine-based ligands bearing structurally different, biologically active heterocyclic moieties was prepared using chromone-3-carboxylic acid, indole-2-carboxylic acid, isoquinoline-1-carboxylic acid, and 1*H*-benzimidazole-2-carboxylic acid. Building on our previous detailed characterisation of the chromone-containing system[3], the protonation and copper(II)-binding properties of these ligands, together with the solution speciation, coordination modes, and SOD-like activity of their copper(II) complexes, were investigated using equilibrium, spectroscopic, and kinetic methods.

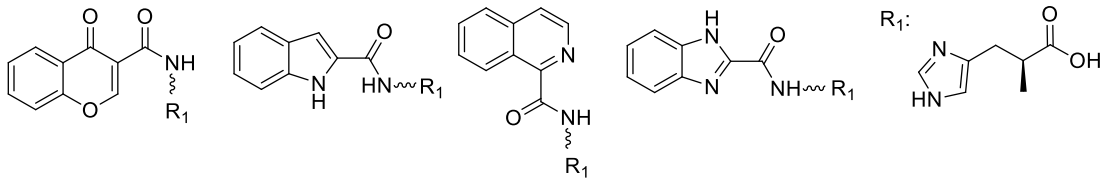

Figure 1. Structures of the investigated histidine-based ligands.

The results demonstrate that the ligands provide effective metal-binding sites for copper(II). At physiological pH, the coordination sphere of the copper(II) ion involves the carboxamide nitrogen, a carboxylate group, the imidazole nitrogen atom of the histidine residue, and either an oxygen donor atom of the O-heterocyclic moiety or nitrogen donor atoms of the N-heterocyclic moiety. The nature of the heterocyclic unit influences the composition, coordination environment, and distribution of the complexes formed in solution.
The SOD-like activity of the copper(II) complexes was evaluated by stopped-flow measurements and the xanthine/xanthine oxidase/NBT assay. The complexes exhibit distinct activities towards superoxide, indicating that the heterocyclic donor unit and the resulting coordination environment strongly influence their reactivity. These findings provide further insight into the relationships among ligand structure, copper(II) speciation, and SOD-like activity and may contribute to the rational design of copper-based antioxidant systems.

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References

[1] Riley, D. P., *Chem. Rev.* **1999**, *99*, 2573-2587.
[2] Preiser, J.-C., *J. Parenter. Enteral Nutr.*, **2012**, *36 (2)*, 147-154.
[3] Szalóki, D. V.; Szabó, M.; Bonczidai-Kelemen, D.; Udvardy, A.; May, N. V.; Kovács, K.; Virág, L.; Fábián, I.; Lihi, N., *Inorg. Chem.* **2025**, *64 (43)*, 21718–21729.

The Reactivity of Cobalt Porphyrinoids toward NO

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Nitric oxide (NO) is a small, reactive molecule of significant biological importance.[1] In living organisms, it acts as a signalling molecule and is involved in many physiological processes, including the regulation of blood vessel tone, neurotransmission and the immune response.[2] Its action stems from its high chemical reactivity and its ability to interact with various biomolecules. Of particular importance are the reactions of nitric oxide with metal centres, especially those containing iron, copper or cobalt. NO can coordinate with metal ions to form complexes with diverse electronic and structural properties. [3]

The study focused on the spectroscopic properties and reaction kinetics of aquacobalamin, cobalt protoporphyrin IX and cobalt chlorophyllide with nitrogen oxide (NO) and the nitroxyl anion (NO^-). The experimental results were supported by molecular modelling using DFT methods. The results showed that both the coordination mode and the reactivity of NO/NO^- are strongly dependent on the oxidation state of the central cobalt atom and on the structural features of the macrocyclic tetrapyrrole ligand. It was found that differences in the electronic properties and coordination environment of the cobalt centres influence the strength and nature of the metal-nitrogen bond, as well as the overall stability and reactivity of the resulting complexes.

Research into the interactions of NO with metal centres and porphyrinoids provides a better understanding of the mechanisms underlying biological processes related to the transport, storage and detoxification of nitric oxide, and is also useful in the design of new compounds of potential biological and medical significance.

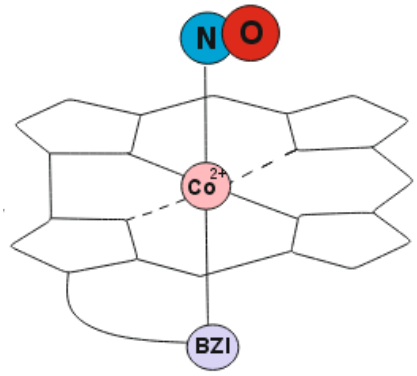

Figure 1. Nitrosocobalamin

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References

1. Andrabi, S. M. *et al.* Nitric Oxide: Physiological Functions, Delivery, and Biomedical Applications. *Advanced Science* vol. 10 Preprint at https://doi.org/10.1002/advs.202303259 (2023).

2. Snyder, S. H. & Bredt, D. S. *Biological Roles of Nitric Oxide*. (1992).

3. Wolak, M., Zahl, A., Schneppensieper, T., Stochel, G. & Van Eldik, R. Kinetics and mechanism of the reversible binding of nitric oxide to reduced cobalamin B12r (Cob(II)alamin). *J. Am. Chem. Soc.* **123**, 9780–9791 (2001).

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