Mach-5 2026

MOLECULAR MACHINERY:
MAKING · MEASURING · MODELLING

6 – 9 September 2026 / Liblice / Czech Republic

https://kaleta.group.uochb.cz/en/mach5-liblice-2026

Sunday, September 6, 2026		Monday, September 7, 2026		Tuesday, September 8, 2026		Wednesday, September 9, 2026	
		7:00	Breakfast	7:00	Breakfast	7:00	Breakfast
		9:00	Ben Feringa	9:00	Michael Howlett	9:00	Jonathon Beves
		9:20		9:20	Xiaoran Hu		
		9:40		9:40	Petr Kovaříček		
		10:00	Shuntaro Amano	10:00	Abhishek Mondal	10:00	Benjamin Roberts
		10:20	Leonardo Andreoni	10:20	Coffee break	10:20	Rebecca Salthouse
		10:40	Carlos Benitez-Martin			10:40	Coffee break
		11:00	Coffee break	11:00	Enzo Olivieri	11:10	Stefan Schröder
				11:20	Emanuele Penocchio	11:30	Zbigniew L. Pianowski
		11:40	Stefan Borsley	11:40	Jacopo Perego	11:50	Andrea Belluati
	Arrival & Registration	12:00	Tessel Bouwens	12:00	Yang Zhang	12:10	Jacob Jan van der Wal
		12:20	Kateřina Bezděková	12:20	Takuma Miyamura	12:20	Closing Remarks
		12:30	Lunch	12:30	Lunch		
		14:40	Artjom Businski	Afternoon	Excursion / Free Time		Departure
		15:00	Jakub Copko				
15:30	Welcome Ceremony	15:20	Stefano Corrà				
15:40	Nicolas Giuseppone	15:40	Massimiliano Curcio				
	Senior SSF Award	16:00	Coffee break				
16:40	Michael Kathan	16:40	Wojciech Danowski				
	Junior SSF Award	17:00	Fabian Eisenreich				
		17:20	Liang Fei				
17:40	Roundtable Discussion	17:40	Yohan Gisbert				
		18:00	Robert Hein				
		18:20	Simona Sophie Capomolla				
18:40	Welcome Reception + Dinner	18:30	Dinner	Evening	Conference Dinner		
		20:00	Poster session				

Location

Hosted at the beautiful Château Liblice, an elegant Baroque château surrounded by a historic park in the peaceful countryside north of Prague, the MACH-5 Conference offers an inspiring setting for scientific exchange and discussion. The château, dating back to the late 17th century, combines its unique historical atmosphere with modern conference facilities, providing an ideal venue for bringing together researchers in the fascinating field of molecular machinery.

Topics

Mach-5 welcomes young scientists active in the field of artificial molecular machines and their components (motors, switches, rotors, actuators, ...).
Contributions are encouraged across the **3M spectrum: modelling, making, and measuring,** as well as studies exploring the functions that emerge when molecular machines are coupled to energy sources or triggers (light, redox, concentration gradients, electric or magnetic fields, etc.) and their interactions with various environments (solution, surfaces, polymers, biological systems, ...).

Scope

Mach-5 aims to provide a dynamic scientific forum on the many theoretical and experimental aspects of molecular machinery. The event is particularly dedicated to the involvement and support of **young investigators** – defined as scientists at the beginning of their independent careers, after the PhD but before obtaining a tenured position.

MACH-5: Molecular Machinery — Making, Measuring, Modelling

Molecular machines have transformed our view of what chemistry can achieve. Molecules can now be designed to rotate, shuttle, pump, transport, assemble, sense, and perform mechanical work in response to light, chemical fuels, electrical or redox stimuli. What began with individual molecular switches and motors has evolved into a broader quest: **how can controlled molecular motion be translated into useful function?**

MACH-5 was created as a forum for addressing this question. The conference series was launched in 2022 at Plön Castle in Germany and continued in 2024 at the historic fortress of Bertinoro in Italy. The third meeting, MACH-5 2026, brings the community to Liblice Castle in the Czech Republic. Across its editions, MACH-5 has brought together researchers working at the forefront of artificial molecular machinery, from molecular motors, switches, rotors, and actuators to molecular pumps, mechanically interlocked molecules, dynamic supramolecular systems, and responsive materials.

The name **MACH-5** reflects the scientific philosophy of the meeting: **Making, Measuring, and Modelling**. These three aspects are inseparable. Sophisticated molecular machines require ingenious molecular design and synthesis, precise experimental methods to observe their operation, and theoretical approaches to understand and predict their behaviour. MACH-5 therefore brings together complementary perspectives on how molecular machinery is created, characterized, and understood.

The meeting also looks beyond molecular machines as isolated objects. How can molecular motion be **controlled, transmitted, amplified, and ultimately converted into function**? These questions connect molecular motors and switches with supramolecular chemistry, materials science, mechanochemistry, and systems chemistry, as well as with emerging biological and technological applications.

A defining feature of MACH-5 is its strong emphasis on **young researchers**. The conference provides scientists at the beginning of their independent careers with an opportunity to present their ideas and discuss them directly with internationally recognized leaders in the field. Rather than separating established scientists from the next generation, MACH-5 aims to create an environment in which scientific exchange is genuinely two-way and where new collaborations and ideas can emerge.

The 2026 meeting at Liblice continues this tradition by bringing together internationally recognized pioneers of molecular machinery and researchers who are now shaping its future. The programme spans the full spectrum of **Making, Measuring, and Modelling**, while the presence of the Sauvage–Stoddart–Feringa Award recipients and other leading scientists provides a unique opportunity for exchange across generations and disciplines.

Ultimately, MACH-5 is built around a simple idea: **molecular machinery is too broad and too rapidly evolving a field to be explored within disciplinary boundaries**. Its progress depends on bringing together synthetic chemists, physical chemists, theoreticians, materials scientists, and researchers interested in biological and technological applications.

For everyone gathered at Liblice, MACH-5 2026 is therefore more than another scientific meeting. It is an opportunity to become part of an international community exploring one of the most intriguing questions in contemporary chemistry:

How can we design matter that does not merely exist,
but moves, responds, and performs work?

A message from the organizers

It is my great pleasure to welcome you to MACH-5 2026 at Liblice Castle. I hope that these few days will provide not only a stimulating scientific programme, but also the time and space for the informal discussions from which new ideas and collaborations often emerge. I am delighted to have you with us and hope you will enjoy both the science and the unique setting of Liblice.

Jiří Kaleta, Ph.D.
Conference Chair

Conference Schedule

Sunday, September 6, 2026		
15:30 – 15:40	Welcome Ceremony	
Chairperson: Jiří Kaleta, Rainer Herges		
15:40 – 16:40	**Senior SSF Award**	
	Nicolas Giuseppone	Using Artificial Molecular Motors to Drive Complex Chemical Systems out-of-Equilibrium
16:40 – 17:40	**Junior SSF Award**	
	Michael Kathan	Inventing Molecular Machines to Explore New Chemical Space
17:40 – 18:40	Roundtable Discussion	
18:40	Welcome Reception + Dinner	
Monday, September 7, 2026		
Chairperson: Alberto Credi		
09:00 – 10:00	**Plenary Lectures**	
	Ben Feringa	The Art of Building Small from Molecular Switches to Motors
10:00 – 10:20	Shuntaro Amano	Network-level Control of Chemoselectivity in a Dynamic Combinatorial Systém
10:20 – 10:40	Leonardo Andreoni	Electrochemically Switchable [C2]Daisy Chains as Prototypes of Molecular Muscles
10:40 – 11:00	Carlos Benitez-Martin	Engineering Photochemical Processes to Drive Multiphoton-Like Fluorescence Responses
11:00 – 11:40	Coffee	
11:40 – 12:00	Stefan Borsley	Functional Work from Nonequilibrium Systems
12:00 – 12:20	Tessel Bouwens	Supramolecular Approaches to Enhance the Power Conversion Efficiency in Artificial Photosynthetic Devices
12:20 – 12:30	Kateřina Bezdekova	Surface-Decoupled Altitudinal and Azimuthal Triptycene-Fused Tetrapodal Molecular Motors
12:30 – 14:40	Lunch	
Chairperson: John Beves		
14:40 – 15:00	Artjom Businski	Bending Away from Light: Diazocine Photoswitches in Liquid-Crystalline Elastomers
15:00 – 15:20	Jakub Copko	Beyond Bistability: Multiplicity-Driven Three-State Photochromic Systém
15:20 – 15:40	Stefano Corra	Light-Fueled Supramolecular Pumps
15:40 – 16:00	Massimiliano Curcio	Light-Driven Artificial Diazene Molecular Rotary Motors
16:00 – 16:40	Coffee	
16:40 – 17:00	Wojciech Danowski	Photoresponsive Porous Solids – from Molecular Design to Function
17:00 – 17:20	Fabian Eisenreich	Switch, Stick, Solidify: Tuning Polymers with Light
17:20 – 17:40	Liang Fei	Photoswitches for Solar Energy Storage and Their Applications
17:40 – 18:00	Yohan Gisbert	Rational Design of Molecular Motors for Single-Molecule Force Experiments

18:00 – 18:20	Robert Hein	Design and Synthesis of Novel Geometric Redox Switches
18:20 – 18:30	Simona Sophie Capamolla	Catalysis by a Metastable Photoswitchable Cage
18:30	Dinner	
20:00	Poster Session	
Tuesday, September 8, 2026		
Chairperson: Stefano Crespi		
09:00 – 9:20	Michael Howlett	Transmission of Autonomous Motion Through a Chemically Driven Molecular Gear
09:20 – 9:40	Xiaoran Hu	Atropisomer Mechanochemistry – Force Triggered Conversion of Atropisomer Stereochemistry
09:40 – 10:00	Petr Kovaříček	Light-Responsive Dynamic Covalent Systems: Out-of-Equilibrium States, Switching and Catalysis
10:00 – 10:20	Abhishek Mondal	Light-Enhanced Chloride Transport by Thiourea-Appended Molecular Motor
10:20 – 11:00	Coffee	
11:00 – 11:20	Enzo Olivieri	From Small Machines to Complex Assemblies
11:20 – 11:40	Emanuele Penocchio	Do Light-Driven Motors Really Work Differently? Kinetic Asymmetry in Photochemistry
11:40 – 12:00	Jacopo Perego	Machinery of Multiple Rotors and Switches in Porous Responsive Architectures
12:00 – 12:20	Yang Zhang	Functional Single-Molecule Super-Resolution Microscopy with Switchable Fluorescent Molecules
12:20 – 12:30	Takuma Miyamura	Spin-State Photoswitching Drives Dual Rotors
12:30 – 13:30	Lunch	
Afternoon	Excursion / Free Time	
Evening	Conference Dinner	
Wednesday, September 9, 2026		
Chairperson: Nadja Simeth-Crespi		
09:00 – 10:00	**Plenary Lectures**	
	Jonathon Beves	Visible Light Responsive Self-Assembly
10:00 – 10:20	Benjamin Roberts	A Brownian Approach to Transport
10:20 – 10:40	Rebeca Salthouse	Engineering Multistate Photoswitches for Molecular Solar Thermal (Most) Energy Storage and Beyond
10:40 – 11:10	Coffee	
11:10 – 11:30	Stefan Schröder	Chemical Vapor Deposited Functional Polymer Thin Films for Light-Driven Actuation and Molecular Machines
11:30 – 11:50	Zbigniev Pianowski	Biocompatible Photochromic Systems: Gels, Cages, and Photopharmacology
11:50 – 12:10	Andrea Belluati	From Reaction Networks to Synthetic Matter in Biological and Cell-Like Systems
12:10 – 12:20	Jacob Jan van der Wal	The Nonadiabatic Nature of the Substituent Effects in Azobenzene
12:20	Closing Remarks	

Prof. Ben L. Feringa

Ben L. Feringa is Jacobus van 't Hoff Distinguished Professor of Molecular Sciences at the University of Groningen, where he has been a leading figure in synthetic organic chemistry for several decades. His research combines organic synthesis, stereochemistry, catalysis, molecular switches and motors, supramolecular chemistry, and systems chemistry, with the overarching aim of creating functional molecular systems capable of controlled motion, recognition, transport, and catalysis.

Feringa's pioneering work established molecular machines as a major field of modern chemistry. In 1999, his group reported the first light-driven unidirectional molecular rotary motor, demonstrating that controlled molecular motion could be generated and sustained at the molecular scale. Subsequent research has developed increasingly sophisticated molecular motors and switches, explored their integration into molecular and supramolecular systems, and investigated how molecular motion can be coupled to chemical work and function. His current research continues to address molecular motors, autonomous motion, molecular systems operating out of equilibrium, and the integration of molecular machines into functional materials and nanoscale devices. For his contributions to the **design and synthesis of molecular machines**, Feringa was awarded the **2016 Nobel Prize in Chemistry**, jointly with Jean-Pierre Sauvage and Sir J. Fraser Stoddart. Among his other major distinctions are the Tetrahedron Prize and the August Wilhelm von Hofmann Medal, both awarded in 2016.

Prof. Jon E. Beves

Jon E. Beves is Professor in the School of Chemistry at the University of New South Wales, Sydney. His research is centred on supramolecular and coordination chemistry, particularly the development of molecular systems whose structure, recognition, reactivity, and function can be controlled by external stimuli. A major focus of his group is the use of visible light to control **photoswitchable molecular devices, supramolecular assemblies, and molecular machines**.

Beves has developed a broad research programme spanning molecular sensors, photoswitchable coordination complexes, self-assembled molecular architectures, molecular cages, and photoresponsive materials. His work is particularly concerned with translating molecular-scale photochemical switching into changes in supramolecular structure and function. Recent research includes photoswitchable molecular cages capable of controlling catalysis, light-responsive self-assembly, photoswitchable amphiphiles with programmable assembly behaviour, and systems in which molecular switching can influence transport and emergent properties at larger length scales.

Beves obtained his PhD from the University of Basel and subsequently carried out postdoctoral research with David Leigh at the University of Edinburgh, before joining UNSW in 2013. He was awarded an **ARC Future Fellowship** in 2017 and was promoted to Professor in 2025. His research provides a distinctive connection between coordination chemistry, photochemistry, supramolecular self-assembly, and molecular machinery.

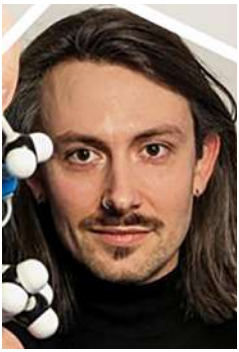
Prof. Nicolas Giuseppone

Nicolas Giuseppone is Professor at the University of Strasbourg and a researcher at the Institut Charles Sadron (CNRS), where he leads the Molecular and Supramolecular Synthesis and Self-Assembly (SAMS) group. His research lies at the interface of **supramolecular chemistry, molecular machines, nanoscience, and materials science**, with a particular emphasis on understanding how controlled molecular motion can be transmitted, amplified, and converted into function at higher length scales.

A central theme of Giuseppone's research is the integration of artificial molecular machines into supramolecular and polymeric architectures. His group has developed molecular actuators and mechanically active supramolecular systems in which molecular motion can be coupled to polymer chains and amplified into macroscopic changes in material properties. These approaches have led to motorized polymers, mechanically active gels, and artificial muscle-like materials, while also providing new strategies for studying the transmission of mechanical work through hierarchical molecular architectures. More recent work explores the use of molecular motors to organize matter at the nanoscale and to create **motorized supramolecular polymers**.

Giuseppone established his independent research group at the Institut Charles Sadron in 2008 and became Professor at the University of Strasbourg in 2016. He is a member of the **Institut Universitaire de France** and was awarded the **CNRS Silver Medal in 2024** in recognition of his internationally recognized contributions to supramolecular chemistry and artificial molecular machines.

Dr. Michael Kathan



Michael Kathan leads the Molecular Machines group at Humboldt-Universität zu Berlin. His research focuses on the design and operation of **artificial molecular machines**, with a particular emphasis on using light-driven molecular motion to perform directed mechanical tasks and, ultimately, to employ molecular machines as tools for chemical synthesis.

Kathan's work has addressed fundamental questions concerning the operation of molecular motors, including the influence of mechanical strain on motor rotation and the integration of light-driven motors into functional molecular and extended architectures. His research has subsequently moved toward exploiting molecular machines to perform tasks that go beyond simple molecular motion. In particular, his group has demonstrated molecular-machine-directed synthesis of mechanically interlocked molecules, including **catenanes and rotaxanes**, in which the machine actively controls the formation of the desired molecular topology. This work represents a significant step towards using artificial molecular machines as synthetic tools capable of accessing structures that are difficult or impossible to obtain by conventional synthetic strategies. Kathan studied chemistry at Freie Universität Berlin and ETH Zürich and completed his doctoral research at Humboldt-Universität zu Berlin. He subsequently worked with Ben Feringa at the University of Groningen before establishing his independent research programme in Berlin. His group is currently supported by the **DFG Emmy Noether Programme**, through which he leads the NanoMECHs project on using molecular machines to manipulate and interlock chemical structures. Among his distinctions are the **Berliner Doktorandenpreis (2019)** and the **Albert Weller Prize (2020)**.

ABSTRACTS

The abstracts are published as submitted by the authors
and have not been subject to linguistic or editorial revision.

Plenary lectures

The Art of Building Small from Molecular Switches to Motors

Ben L. Feringa

University of Groningen, Stratingh Institute for Chemistry, Faculty of Science and Engineering, Nijenborgh 4, 9747 AG, Groningen, The Netherlands.

Abstract:
The fascinating molecular motors and machines that sustain life offer a great source of inspiration to the molecular explorer at the nanoscale. Among the major challenges ahead in the design of complex artificial molecular systems and is the control over dynamic properties and responsive far-from-equilibrium behavior. Chemical systems and adaptive materials ultimately require integration of structure, organization and function of multi-component dynamic molecular assemblies at different hierarchical levels. A major goal is to achieve and exploit translational and rotary motion. In this presentation the focus is on the dynamics of functional molecular systems and machines as well as triggering and assembly processes. We design switches and motors in which molecular motion is coupled to specific functions. Responsive behavior will also be illustrated in self--assembly and responsive materials with a focus on cooperative action, amplification along multiple length scales and 2D and 3D organized systems. The design, synthesis and functioning of rotary molecular motors and machines will be presented with a prospect toward future dynamic molecular systems and materials.

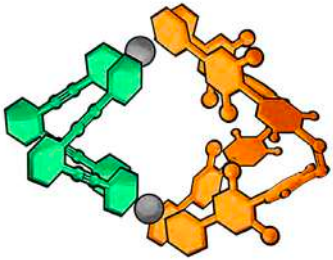
Information on http://www.benferinga.com
- Molecular Machines: *Nature, September 2015*
- Molecular Switches: *Chemistry World, June 2016*
- *Vision statement* "Materials in Motion": Adv. Mater. 2020

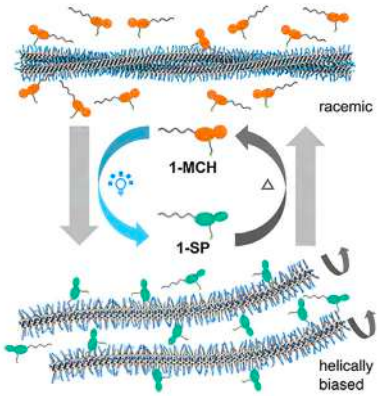
Visible Light Responsive Self-Assembly

Jonathon E. Beves,[a] Simona S. Capomolla,[a] Man Him Chak,[a] Ray DiNardi,[a]
Samina Rasheed,[a] Laura Wimberger[a]

[a]*School of Chemistry, UNSW Sydney, Australia*

Our latest results will be presented, where we design self-assembled systems and manipulate them using visible-light-responsive photoswitches.
Building on our previous work,[1] we have prepared heteroleptic metastable assemblies that are assembled upon irradiation with green light and are catalytically active.[2] We have also used visible light to control the assembly of DNA,[3] large micelle-like structures,[4] and the asymmetry of self-assembled fibres,[5] revealing complex non-equilibrium behaviour that persists hours after the irradiation is switched off. We are now beginning to explore how assembly kinetics can give rise to functions that evolve over time, as well as how to address the challenges involved in designing and studying such systems.





REFERENCES

1. R. G. DiNardi, S. Rasheed, S. S. Capomolla, M. H. Chak, I. A. Middleton, L. K. Macreadie, J. P. Violi, W. A. Donald, P. J. Lusby, J. E. Beves. *J. Am. Chem. Soc.* **2024**, 31, 21196–21202.
2. S. S. Capomolla, C. M. Leonhardt, S. Rasheed, J. Violi, W. A. Donald, P. J. Lusby, J. E. Beves. *ChemRxiv* **2026**. DOI: https://doi.org/10.26434/chemrxiv.15003829/v3
3. L. Wimberger, F. Rizzuto, J. E. Beves, *J. Am. Chem. Soc.* **2023**, *145*, 2088–2092.
4. M. H. Chak, L. Wimberger, B. Richardson, N. E. Newman, E. M. V. Johansson, J. P. Violi, A. Sokolova, H. Frisch, F. J. Rizzuto, W. A. Donald, M. H. Stenzel, J. Andréasson, J. E. Beves, *Chem. Eur. J*, **2025**, 31, e02399.
3. M. H. Chak, F. V. de Graaf, R. Bellan, J. P. Violi, W. A. Donald, G. Vantomme, E. W. Meijer, J. E. Beves. *J. Am. Chem. Soc.* **2026,** *148*, 16223–16231.

SSF Award

Using artificial molecular motors to drive complex chemical systems out-of-equilibrium

Nicolas Giuseppone[a]

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Institut Charles Sadron - CNRS, 23 rue du Loess, BP 84047
67034 Strasbourg Cedex 2, France.

Inspired by the protein machinery found in biological systems, and based on the theoretical understanding of the physics of motion at nanoscale, organic chemists have developed a number of molecules that can actuate when triggered by various external chemical or physical stimuli. In particular, basic molecular switches that commute between (meta)stable states, and more advanced molecular motors that produce unidirectional cyclic motions, have been reported. However, the integration of individual molecular motors in a continuous out-of-equilibrium mechanical process that can produce mechanical work at various length scales and up to the macroscale remains an important area to explore.[1,2] We will discuss advances developed by our group on the collective actuation of artificial molecular motors, which involve their mechanical coupling with polymer and supramolecular self-assemblies. We will show how it becomes possible to integrate them and to make use of their autonomous mechanical work to drive endoenergetic processes in complex systems and active materials.

REFERENCES

1. D. Dattler, G. Fuks, J. Heiser, E. Moulin, A. Perrot, Y. Xuyang, N. Giuseppone, *Chem. Rev.* **2020**, *120*, 310-443.
2. E. Moulin, L. Faour, C. Carmona-Vargas, N. Giuseppone, *Adv. Mat.* **2020**, 201906036.

Inventing molecular machines to explore new chemical space

Michael Kathan[a]

[a]*Department of Chemistry, Humboldt-Universität zu Berlin, Brook-Taylor-Str. 2, 12489 Berlin, Germany.*

Precise mechanical manipulation of molecules is inherently difficult due to random thermal motion. Although directed motion at the molecular scale has been achieved, harnessing it to impose specific molecular shapes and construct mechanically interlocked structures remains a fundamental challenge.

In this presentation, we report the synthesis of mechanically interlocked molecules – namely catenanes, molecular knots and rotaxanes – enabled by a molecular motor that winds molecular strands into discrete entangled structures, each defined by a specific number of mechanical crossings.[1,2]

Light energy drives the unidirectional rotation of the molecular motor, enabling path-dependent control over a sequence of thermodynamically disfavored yet mechanically distinct and kinetically stable winding states. These states are covalently captured and subsequently released to yield mechanically interlocked molecules.

This machine-directed approach provides a general proof-of-concept strategy for the template-free construction of mechanically interlocked molecules that are unattainable by other means, thereby expanding the scope of organic synthesis and enabling access to new chemical space.

REFERENCES

1. Wachsmuth, T.; Kluifhooft, R.; Müller, M.; Zeiß, L.; Kathan, M.A. molecular machine directs the synthesis of a catenane. *Science* **2025**, *389*, 526–531.
2. Kluifhooft, R.; Wachsmuth, T.; Barthel, B.; Müller, M.; Rückert, A.-K.; Kathan, M.A. molecular machine directs the synthesis of a rotaxane. *Angew. Chem. Int. Ed.* **2026**, *65*, e20085.

Invited talks

Network-level Control of Chemoselectivity in a Dynamic Combinatorial System

Zhipeng Li,[a,b] Shuntaro Amano,[a,c,*] Shaymaa Al Shehimi,[a] Malak Jaber,[a] Leonardo Andreoni,[d] Serena Silvi,[d,*] Zhong-Yuan Lu,[b,*] and Giulio Ragazzon[a,*]

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[b]*State Key Laboratory of Supramolecular Structure and Materials, College of Chemistry, Jilin University, Changchun 130012, China.*
[c]*Department of Chemical Engineering, Delft University of Technology, Mekelweg 5, 2628 CD, Delft, The Netherlands.*
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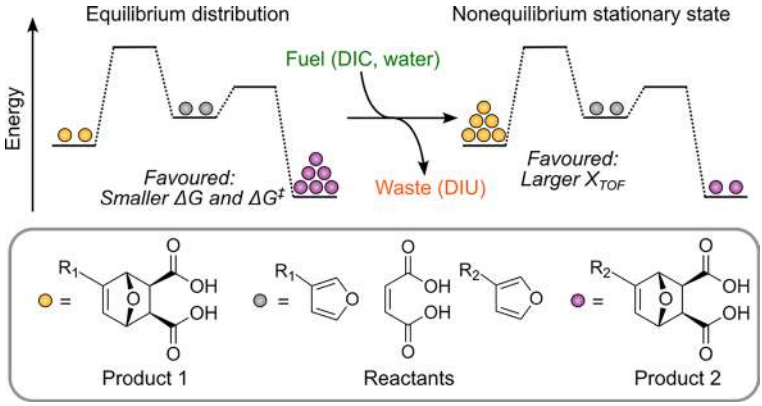

The ability to control the composition of complex reaction networks is a hallmark of biological functions such as metabolism. However, such control remains challenging to realize synthetically under out-of-equilibrium conditions. Here, we demonstrate selectivity control in a network of competing endergonic Diels-Alder reactions. Based on our previous work,[1] we constructed a new system in which two furan derivatives compete for a shared dienophile (maleic acid) to form Diels-Alder adducts. Coupling this thermodynamically unfavorable process to the hydration of *N*,*N*'-diisopropylcarbodiimide as a chemical fuel drives the system out of equilibrium. Strikingly, under continuous fuelling, the chemoselectivity between competing adducts could be inverted relative to equilibrium. Theoretical studies and sensitivity analysis based on kinetic models revealed how individual rate constants collectively determine nonequilibrium selectivity. In particular, the analysis with a kinetic barrier diagram[2] revealed a parameter related to the distribution at the nonequilibrium stationary state (X_{TOF}). These analyses also uncovered counterintuitive behaviours such as negative differential responses—emergent properties that only arise from the network as a whole. This work establishes a viable strategy for controlling chemoselectivity in complex reaction networks such as dynamic combinatorial libraries driven out of equilibrium. It opens a route toward synthetic reaction networks that, like biological metabolism, adapt their composition through energy consumption.

REFERENCES

1. Al Shehimy, S.; Le, H.-D.; Amano, S.; Di Noja, S.; Monari, L.; Ragazzon, G. Progressive Endergonic Synthesis of Diels-Alder Adducts Driven by Chemical Energy. *Angew. Chem. Int. Ed.* **2024**, *63* (45), e202411554.
2. Penocchio, E.; Ragazzon, G. Kinetic Barrier Diagrams to Visualize and Engineer Molecular Nonequilibrium Systems. *Small* **2023**, *19* (14), 2206188.

Electrochemically Switchable [*C2*]Daisy Chains As Prototypes Of Molecular Muscles

Leonardo Andreoni,[a,b] Jessica Groppi,[b,c] Christian Camilo Carmona-Vargas,[d] Damien Dattler,[d] Lara Faour,[d] Emilie Moulin,[d] Serena Silvi,[b,e] Nicolas Giuseppone[d] and Alberto Credi[a,b]

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Mechanically interlocked molecules constitute a versatile platform for the development of artificial molecular machines, capable of performing controlled mechanical motion in response to external stimuli. Among them, [*c2*]daisy chain rotaxanes are particularly attractive because the translational motion of their macrocycles results in the contraction and the extension of the overall structure, making them promising building blocks for artificial muscles and responsive materials.[1] Here, we report a novel family of bistable [*c2*]daisy chains based on crown ether macrocycles and axle components incorporating redox-active recognition sites. The system initially adopts an extended co-conformation, in which the macrocycles surround the primary redox-active stations. The reduction of the latter induces the shuttling of the macrocycles towards the secondary stations; the subsequent re-oxidation of the primary stations induces the return of the macrocycles on the latter. Thanks to this mechanism, the [*c2*]daisy chains can be switched reversibly between an extended and a contracted state upon electrochemical stimulation. In order to amplify the extent of the actuation, the same switching unit was incorporated into covalent poly-[*c2*]daisy chains, in which multiple molecular machines are connected to form a polymeric backbone. This polymeric system retains the same properties observed for the monomeric daisy chains: the repeating units can be reversibly switched between the extended and contracted states upon reduction and re-oxidation of the redox-active stations. Thanks to these excellent switching capabilities, the developed system is a promising candidate for the realization of electrically driven artificial muscles, capable of amplifying molecular motion at larger length scales. Financial support from the European Union's Horizon 2020 research and innovation program (FET-OPEN "Magnify" 801378) is gratefully acknowledged.

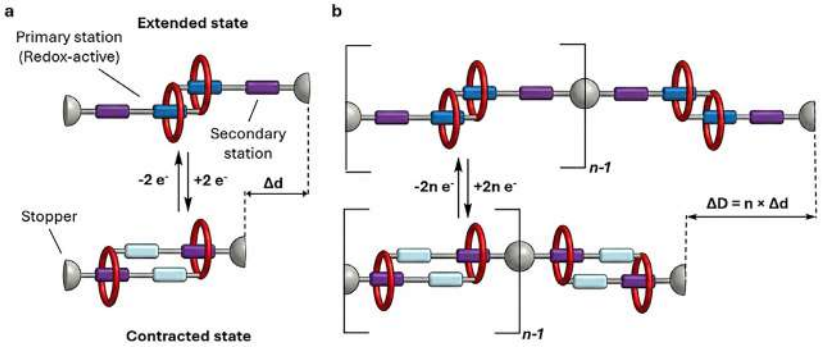

Figure 1. Schematic representation of the [*c2*]daisy chain (**a**) and of the poly-[*c2*]daisy chain (**b**) rotaxanes, together with the electrochemical switching between the extended and contracted states.

REFERENCES

1. Moulin, E.; Carmona-Vargas, C. C.; Giuseppone, N. Daisy Chain Architectures: From Discrete Molecular Entities to Polymer Materials. *Chem. Soc. Rev.* **2023**, *52* (21), 7333–7358.

From Reaction Networks to Synthetic Matter in Biological and Cell-Like Systems

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Living systems continually convert chemical reaction networks into spatial organization and function. Reproducing this coupling with synthetic macromolecular matter requires more than biocompatible chemistry: reactions must generate, reorganize, and control material states in situ. We use biocatalytic controlled radical polymerization as a route to couple synthetic polymer formation directly to biological and biomimetic environments.

In one implementation, an enzymatic reaction network combines horseradish peroxidase-mediated bioATRP with orthogonal and antagonistic enzymatic modules to synthesize poly(dimethylaminoethyl methacrylate) (PDMAEMA) and regulate its ATP-driven complex coacervation. Polymer synthesis, condensation, and dissolution can thereby be temporally coupled, producing transient compartments with state-dependent cargo partitioning.[1] At biological interfaces, surface-displayed horseradish peroxidase on Saccharomyces cerevisiae catalyses surface-initiated controlled radical polymerization, enabling living cells to construct synthetic polymer layers on themselves and demonstrating that cellular machinery can directly participate in its own synthetic modification.[2]

Under confinement, biocatalytic polymerization-induced self-assembly (bioPISA) allows polymerization itself to generate vesicular compartments.[3] Building on this chemistry, we recently coupled a second in situ polymerization inside polymersomes to coacervation-driven, non-lytic export of the newly synthesized macromolecule. Phase separation converts soluble PDMAEMA into a transport-competent condensed state that crosses the polymer membrane without membrane-fusion machinery, while enzymatic polyphosphate cleavage reverses condensation after release. Thus, a reaction-generated material transition can perform an exocytosis-like transport function.[4]

Together, these systems illustrate a progression from reaction-driven polymer synthesis, through transient organization and biological coupling, to compartment-level transport. More broadly, they motivate the engineering of xenoreactomes: reaction spaces in which biological catalysts and synthetic chemistry jointly generate structures and functions beyond those accessible to native metabolism.

REFERENCES

1. Sharma, S.; Belluati, A.; Kumar, M.; Dhiman, S. Enzymatic Reaction Network-Driven Polymerization-Induced Transient Coacervation. Angew. Chem. Int. Ed. 2025, 64, e202421620.
2. Belluati, A.; et al. Self-Decorating Cells via Surface-Initiated Enzymatic Controlled Radical Polymerization. Nanoscale 2023, 15, 19486-19492.
3. Belluati, A.; Jimaja, S.; Chadwick, R. J.; et al. Artificial Cell Synthesis Using Biocatalytic Polymerization-Induced Self-Assembly. Nat. Chem. 2024, 16, 564-574.
4. Naderi Ahranjani, R.; Bacha, S.; Bagherabadi, M.; Kulkarni, K. D.; et al. Inside Job: Synthetic Exocytosis Driven by In Situ Coacervation in Polymersome Artificial Cells. ChemRxiv 2026. DOI: 10.26434/chemrxiv.15005096/v1.

Engineering photochemical processes to drive multiphoton-like fluorescence responses

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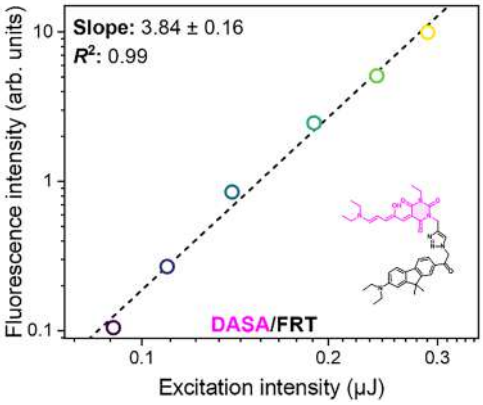
We demonstrated that an improved non-linear fluorescence response is accessible when covalently attaching a P-type photoswitch to a two-photon absorbing probe. The reported system exhibited a performance comparable to what is expected for a four-photon absorbing dye, which is accomplished *via* a sequence of two two-photon processes: two-photon induced FRET sensitized isomerization followed by two-photon excited fluorescence.[1] However, the enhanced response of this "first generation" system was limited to the first instances of the photochromic conversion. This issue was due to the accumulation of the fluorescent species in the medium, leading to a regular two-photon absorbing behavior. To address this limitation, we envisaged that the introduction of a negative T-type photoswitch would prevent the saturation of the system. Thereby, we expect the "second generation" systems to revert thermally to the non-fluorescent form, which would allow keeping the four-photon like fluorescence response at all times.[2,3] These systems are particularly promising in multiphoton microscopy applications, where the spatial resolution depends exponentially on the number of photons involved in the excitation.



Double logarithmic plot of fluorescence intensity vs. excitation intensity for a photoswitch/two-photon absorbing probe dyad showing a four-photon-like fluorescence response.

REFERENCES

1. C. Benitez-Martin, S. Li, A. Dominguez-Alfaro, F. Najera, E. Perez-Inestrosa, U. Pischel, J. Andréasson. *J. Am. Chem. Soc.* **2020**, *142,* 14854–14858.
2. C. Benitez-Martin, J. Rouillon, E. Fron, F. De Jong, M. Grøtli, J. Hofkens, U. Pischel, J. Andréasson. *Nat. Commun.* **2025**, *16*, 10897
3. J. Oh, C. Benitez-Martin, E. Fron, J. Hofkens, U. Pischel, M. Grøtli, J. Andréasson. *J. Am. Chem. Soc.* **2026**, *148,* 20813-20820

Surface-Decoupled Altitudinal And Azimuthal Triptycene-Fused Tetrapodal Molecular Motors

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Light-driven molecular motors are promising building blocks for molecular machinery, yet their integration into surface-mounted systems requires molecular architectures that simultaneously ensure controlled orientation, stable surface attachment, and preservation of photoresponsive function.[1,2] Here we present two triptycene-based tetrapodal molecular motors with rotational axes oriented either nearly parallel (altitudinal) or perpendicular (azimuthal) to a gold surface.[3] The rigid tetrapodal scaffold provides stable surface attachment while electronically decoupling the photoactive motor from the metallic substrate. Both motors undergo efficient unidirectional 360° rotation in solution, reaching photostationary states of around 90% and exhibiting thermal helix inversion half-lives of 7 min at 20 °C (Figure 1). Importantly, the surface-mounted motors retain their full light-driven rotary function, with thermal isomerization kinetics nearly identical to those measured in solution, demonstrating efficient electronic decoupling by the tetrapodal scaffold and establishing these systems as promising platforms for future surface-mounted molecular machinery.

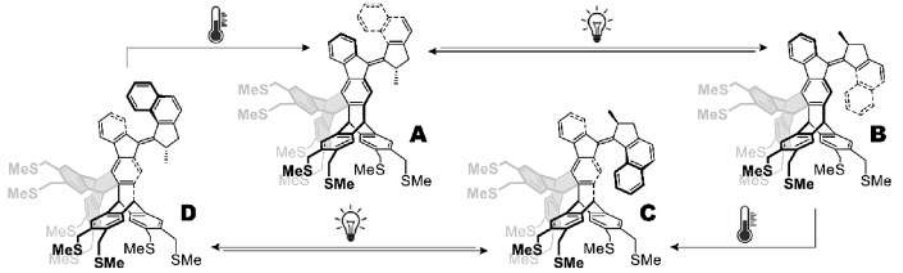

Figure 1: Four-stage 360° rotation cycle of the altitudinal (1, foreground) and azimuthal (2, background) molecular motors

REFERENCES

1. García-López, V.; Liu, D.; Tour, J. M. Light-Activated Organic Molecular Motors and Their Applications. *Chem. Rev.* **2020**, *120*, 79–124.
2. Kaleta, J. Molecular Switches and Motors in 2-D. In *Molecular Photoswitches: Chemistry, Properties, and Applications*; Pianowski, Z. L., Ed.; Wiley-VCH GmbH: Weinheim, Germany, **2022**; pp 711–733.
3. Bezděková, K.; Severa, L.; Kaletová, E.; Majerová Varga, K.; Mašát, M.; Wu, L.-T.; Jiang, J.-C.; Císařová, I.; Kaleta, J. Surface-Decoupled Altitudinal and Azimuthal Triptycene-Fused Tetrapodal Molecular Motors. *Angew. Chem. Int. Ed.* **2026**, *65*, e202513922.

Functional work from nonequilibrium systems

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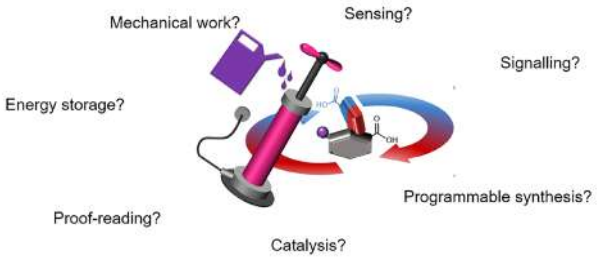
We already know that a functional molecular machine-based nanotechnology capable of driving and sustaining systems away from equilibrium is possible; it is called biology. By continuously dissipating energy, biology moves, stores and transduces energy, senses and signals, processes information, and performs synthesis in a fundamentally different manner to simple equilibrium pathways.[1] Despite advances in the design and synthesis of artificial molecular machines, exploiting genuinely nonequilibrium behaviour (beyond simple switching) remains limited. Indeed, many of the most compelling examples of useful nonequilibrium function have emerged not from molecular machine research itself, but from broader areas of chemistry including deracemization, artificial photosynthesis and systems chemistry.[2] While the opportunities for nonequilibrium task performance are enormous, so too is the gap between the capabilities of our current artificial systems and those of even the simplest living organisms.



In this talk, we will explore both the challenges and the opportunities of harnessing nonequilibrium chemistry to perform useful work. We will consider how molecular systems capture, store, transduce and dissipate energy, and how these principles might be used to create useful function. Finally, I will highlight our own rudimentary efforts to exploit compartmentalised chemical systems as platforms for energy storage, energy transduction, and the control of assembly pathways.3

REFERENCES

1. Borsley, S.; Leigh, D. A.; Roberts, B. M. W. Molecular ratchets and kinetic asymmetry: giving chemistry direction. *Angew. Chem. Int. Ed.* **2024**, *63*, e202400495.
2. Borsley, S.; Gallagher, J. M.; Leigh, D. A.; Roberts, B. M. W. Ratcheting synthesis. *Nat. Rev. Chem.* **2024**, *8*, 8–29.
3. Baxter, W.; Bickerton, L. E.; Liang, K.; Penocchio, E.; Aguilar, J. A.; Ragazzon, G.; Borsley, S. Chemically fueled active transport cascades in large unilamellar vesicles. *J. Am. Chem. Soc.* **2026**. DOI: 10.1021/jacs.6c11418

Supramolecular approaches to enhance the power conversion efficiency in artificial photosynthetic devices

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Noncovalent interactions are widely used in nature to direct fundamental biological and chemical processes, as for example noncovalent bonds enable the effective transfer of protons and electrons in photosynthetic systems. Achieving the same level of control in artificial photosynthetic systems remains extremely challenging. As a result, the transfer of multiple electrons and protons impose major limitations on redox catalysis in synthetic systems.
In this work, we explore how supramolecular interactions can be used to control charge transfer in artificial photosynthetic and photoelectrochemical systems. First, we employed pseudorotaxane architectures as molecular charge rectifiers in dye-sensitised solar cells.[1–3] These systems consisted of a molecular thread connected to a photosensitiser and a macrocyclic electron acceptor positioned close to the dye, preorganised to accept an electron. Upon electron transfer the ring physically moves away from the dye creating a charge separated state.

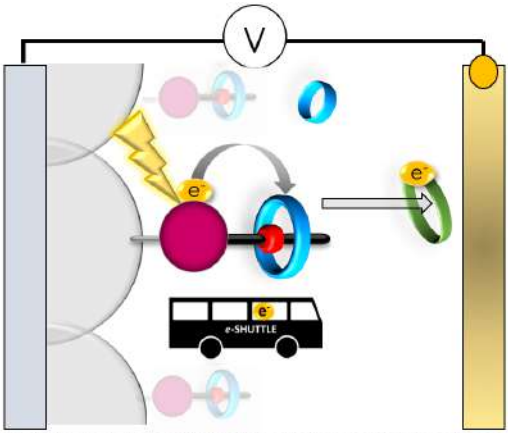

Fig 1: *Schematic representation of design electron shuttle based on a pseudorotaxane for charge rectification in photoelectrochemical cells*

Building on these studies of electron-transfer control, our current research focuses on redox transformations that require the coordinated transfer of both electrons and protons. Similar to the noncovalent strategy inpsired by nature, we continue to exploit supramolecular interactions as a design principle, now specifically through dynamic hydrogen-bonding that emulate the way biological systems organise proton and electron transfer. Our current work employs (photo)redox--responsive hydrogen bonds to preorganise molecular components to undergo effective transfer of protons and electrons, thereby acting as proton-electron shuttles. Ultimately, this approach aims to enable more selective and efficient routes towards fine and speciality chemicals using synthetic photoelectrochemistry.

REFERENCES

1. Bouwens, T.; Bakker, T, M.A.; Hasenack, J.; Dieperink, M.; Zhu, K.; Brouwer, A. M.; Huijser, A.; Mathew, S.; Reek, J. N. H. Using supramolecular machinery to engineer directional charge propagation in photoelectrochemical devices. *Nature Chem.* **2023**, *15*, 213–221.
2. Bouwens, T.; Bakker, T, M.A.; Zhu, K.; Huijser, A.; Mathew, S.; Reek, J. Rotaxane Dye Design in p--Type Dye-Sensitized Solar Cells for Charge-Rectification in photoelectrochemical devices, *Adv. Sci.* **2023**, *2306032*.
3. Bouwens, T.; Mathew, S.; Reek, J. P-Type Dye-Sensitized Solar Cells Based on Pseudorotaxane Mediated Charge-Transfer, *Faraday Discuss.,* **2019**, *215,* 393–406.

Bending Away from Light: Diazocine Photoswitches in Liquid-Crystalline Elastomers

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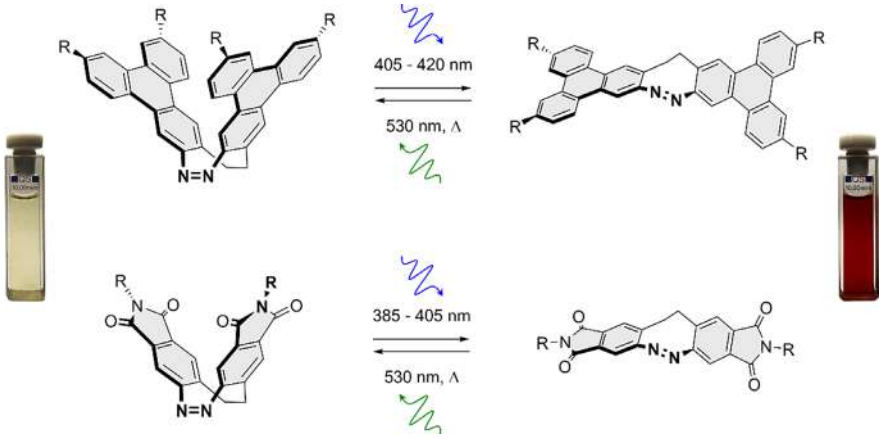
Among the most common photoswitches, azobenzenes are arguably the best-researched systems with applications ranging from biology and photopharmacology to material science. Although derivatives such as azoheteroarenes or BF_2-coordinated azobenzenes show improved photophysical properties, the *E* isomer usually remains the thermodynamically stable form, with *Z* being the metastable isomer. Due to its eight-membered central ring system, this isomer stability is inverted in diazocine, which opens up new actuation modes in photoresponsive materials.
Building on this property, this presentation reports on novel diazocine derivatives with improved molecular geometries toward application in liquid-crystalline elastomers (LCEs). By rigid extension of the switch along its bending axis, the switching amplitude was increased by a factor of up to 3 compared to parent diazocine. Using an acrylate-functionalized derivative, LCE films were prepared and their actuation mechanism was further studied. Unlike azobenzene-based films, the diazocine-containing films bend away from the light source upon isomerization to the metastable state. The actuation mechanism is attributed to an isothermal phase transition driven by a photo-induced increase in liquid-crystalline order.



REFERENCES
1. Businski, A.; Ta, T. C.; Unterriker, L.; Gindullis, N.; von Glasenapp, J.-S.; Näther, C.; Herges, R. Synthesis and Properties of Cyclic Imide Extended Diazocines: Tweezer-Like, Rigid Photoswitches with Large Switching Amplitudes. *Chem. Eur. J.* **2025**, *31*, e202500435.
2. Businski, A.; Hugenbusch, D.; Ta, T. C.; Tayaran, R.; Unterriker, L.; von Glasenapp, J.-S.; Näther, C.; Herges, R. Triphenylene Diazocines: Butterfly-Type Rigid Photoswitches with Annulated Aromatic Ring Systems and Increased Switching Amplitude. *Org. Lett.* **2026**, *28*, 1-6.
3. Näther, C.; Businski, A.; Herges, R. Reversible Phase Transition in 8,19-Dimethyl-2,3,8,19-tetraazapentacyclo[13. 7. 0.0^{4,12}.0^{6,10}.0^{17,21}]docosa-1(15),2,4(12),5,10,16,21-heptaene-7,9,18,20-tetrone. *Acta Cryst. E* **2025**, *81*, 476-481.

Catalysis by a metastable photoswitchable cage

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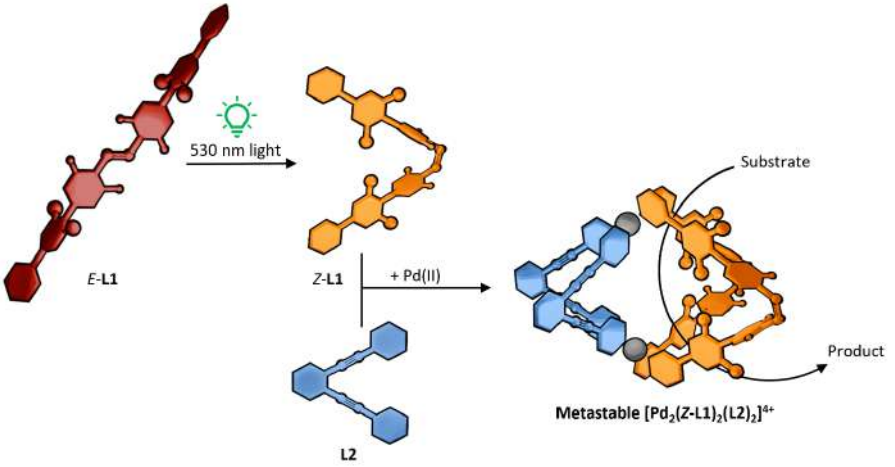
Ortho-fluoro azobenzene ligands are efficient building blocks in light-sensitive metallo--supramolecular self-assemblies. Based on previous work in our group[1-3] I will present the first example of a self-assembled heteroleptic cage containing a photoswitchable azobenzene-derived ligand in its metastable *Z*-isomeric form (***Z*-L1**) and a non-switchable shape-complementary ligand (**L2**). The lantern-shaped metastable [$\mathbf{Pd_2(}$***Z*L1**$\mathbf{)_2(L2)_2}]^{4+}$ cage is only accessible after light--irradiation with 530 nm light, offering an attractive out-of-equilibrium system. Once assembled, the heteroleptic metastable cage can encapsulate substrates for a variety of catalytic reactions including the Michael addition, as well as a nitroaldol reaction. The fact that the catalytically active cage is only formed after light irradiation allows us to control chemical reactions using a non--invasive method.[4]



REFERENCES

1. Kennedy, A. D. W.; DiNardi, R. G.; Fillbrook, L. L.; Donald, W. A.; Beves, J. E., Visible-Light Switching of Metallosupramolecular Assemblies**. *Chem.– Eur. J.* **2022,** *28* (16), e202104461.
2. DiNardi, R. G.; Douglas, A. O.; Tian, R.; Price, J. R.; Tajik, M.; Donald, W. A.; Beves, J. E., Visible--Light-Responsive Self-Assembled Complexes: Improved Photoswitching Properties by Metal Ion Coordination. *Angew. Chem. Int. Ed.* **2022,** *61* (38), e202205701.
3. DiNardi, R. G.; Rasheed, S.; Capomolla, S. S.; Chak, M. H.; Middleton, I. A.; Macreadie, L. K.; Violi, J. P.; Donald, W. A.; Lusby, P. J.; Beves, J. E., Photoswitchable Catalysis by a Self-Assembled Molecular Cage. *J. Am. Chem. Soc.* **2024,** *146* (31), 21196–21202.
4. Capomolla, S. S.; Leonhardt, C. M.; Rasheed, S.; Violi, J. P.; Donald, W. A.; Lusby, P. J.; Beves, J. E., Catalysis by a metastable photoswitchable cage. *Submitted*, DOI: 10.26434/chemrxiv.15003829/v4

Beyond Bistability: Multiplicity-Driven Three-State Photochromic System

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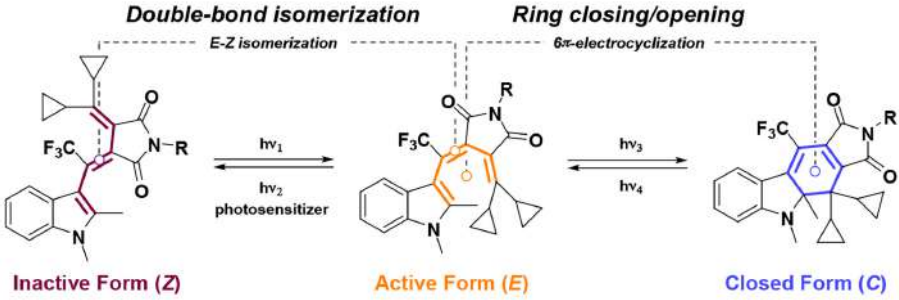
Photochromic molecules typically rely on a single photochemical mechanism, limiting the types of structural changes that can be induced by light.[1] Fulgides offer a unique alternative by combining two fundamentally different photochromic processes within a single molecular framework: *E–Z* double-bond isomerization and reversible 6π-electrocyclization. Together, these processes provide access to three distinct photochromic states. However, up to this point, efforts have primarily focused on suppressing double-bond isomerization in favour of electrocyclization. Instead, we explored whether the two pathways could be controlled independently and used to unlock the full potential of this three-state system.[2]

We addressed this challenge by exploiting the multiplicity of the excited state as a key determinant of photoinduced reactivity. While initially relying on an external sensitizer, this approach ultimately led to the development of a unimolecular three-state photoswitch through a deeper understanding of the requirements governing the sensitization process.[3]

Beyond the development of a single three-state photoswitch, this work showcases the power of excited-state multiplicity in controlling photochemical pathways. We anticipate that this concept can pave the way toward more sophisticated photoswitches with multiple, independently addressable functions.

Scheme 1. Three-state photoswitching between fulgimide isomers.



REFERENCES

1. A. Goulet-Hanssens, F. Eisenreich, S. Hecht, *Advanced Materials,* **2020**, 32, 1905966.
2. J. Copko, T. Slanina, *Chem. Commun.* **2024**, 60, 3774.
3. J. Copko, L. Ludvíková, T. Slanina, *Chem. Eur. J.,* **2025**, 31, e202500678.

Light-Fueled Supramolecular Pumps

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Natural and artificial autonomous molecular machines operate by constantly dissipating energy from an external source to maintain a non-equilibrium state. The in-depth study of these dissipative states is highly challenging as they exist only as long as energy is provided.[1]
We reported on a series of (supra)molecular systems that use light to shift a closed (photo)reaction network away from thermodynamic equilibrium thanks to a ratchet mechanism transducing light energy into chemical energy.[2] On top of that, these molecular ratchets can rectify the Brownian motion of the components and store energy building up concentration gradients.[3]
In this talk the structural evolution and the kinetics and energetic aspects of this family of (supra) molecular motors will be discussed along with the advancements of the analytical techniques required to reach an unprecedented insight in the real-time operation of non-equilibrium (photo) chemical reaction networks.

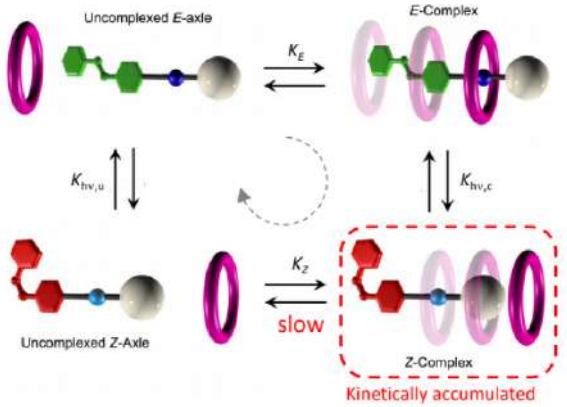

Figure 1. Closed reaction cycle travelled clockwise by a supramolecular pump during operation (dashed arrow). *Z*-complex is kinetically accumulated away from its (local) equilibrium concentration.

REFERENCES

1 a) Baroncini, M., Silvi, S., Credi, A. *Chem. Rev.* **2020**, *120*, 200–268; b) Mattia, E., Otto, S. *Nat. Nanotech.* **2015**, *10*, 111–119.
2 a) Ragazzon, G., Baroncini, M., Silvi, S., Venturi, M., Credi, A. *Nat. Nanotech.* **2015**, *10*, 70–75; b) Corra, S., Casimiro, L., Baroncini, M., Groppi, J., la Rosa, M., Tranfić Bakić, M., Silvi, S., Credi, A. *Chem. Eur. J.* **2021**, *27*, 11076–11083; c) Canton, M., Groppi, J., Casimiro, L., Corra, S., Baroncini, M., Silvi, S., Credi, A. *J. Am. Chem. Soc.* **2021**, *143*, 10890–10894; d) Corra, S., Tranfić Bakić, M., Groppi, J., Baroncini, M., Silvi, S., Penocchio, E., Esposito, M., Credi, A. *Nat. Nanotech.* **2022**, *17*, 746–751.
3 Nicoli, F., Taticchi, C., Corra, S., Tranfić Bakić, M., Baroncini, M., Silvi, S., Groppi, J., Credi, A. *Angew. Chem. Int. Ed.* **2026**, *65*, e8103353.

Light-driven artificial diazene molecular rotary motors

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Artificial molecular motors are at the forefront of research in nanotechnology due to their ability to perform tasks by harnessing directionally controlled motion at the molecular scale.[1] The development of light-driven nanomotors is a particularly challenging task that holds great potential for future sunlight-powered systems and active materials.[2] Our research efforts have recently been directed to the establishment of a novel class of photochemical molecular rotary motors based on diazene photoswitches that operate along triangular reaction cycles exploiting the formation of diastereomeric species through photoisomerisation-generated axial chirality (Figure 1a).[3] The different thermal stability and photochemical reactivity of these diastereomers permit net directional motion combining a thermal rotation about a C–N single bond and two light-induced configurational rearrangements (Figure 1 b). Crucially, the composition of the dissipative state sustained upon continuous supply of light is highly dependent on the irradiation wavelength, and as a result the preferred rotation direction can be inverted (Figure 1c).

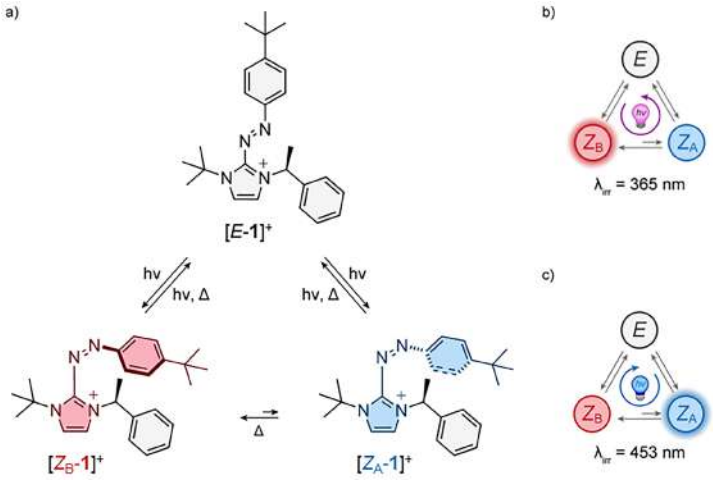

Figure 1. a) Triangular closed reaction network of operation and b) counter-clockwise or c) clockwise net directional travel along the network upon irradiation at 365 nm or 453 nm, respectively.

REFERENCES

1. Kassem, S.; van Leeuwen, T.; Lubbe, A. S.; Wilson, M. R.; Feringa, B. L.; Leigh, D. A. Artificial Molecular Motors. *Chem. Soc. Rev.* **2017**, *46*, 2592-2621.
2. Baroncini, M.; Silvi, S.; Credi, A. Photo- and Redox-Driven Artificial Molecular Motors. *Chem. Rev.* **2020**, *120*, 200-268.
3. Nicoli, F.; Taticchi, C.; Lorini, E.; Borghi, S.; Aleotti, F.; Silvi, S.; Credi, A.; Garavelli, M.; Muccioli, L.; Baroncini, M.; Curcio, M. Wavelength-steered directional rotation in an autonomous light-driven molecular motor. *Nat. Chem.* **2026**, *18*, 1171-1177.

Photoresponsive Porous Solids – From Molecular Design to Function

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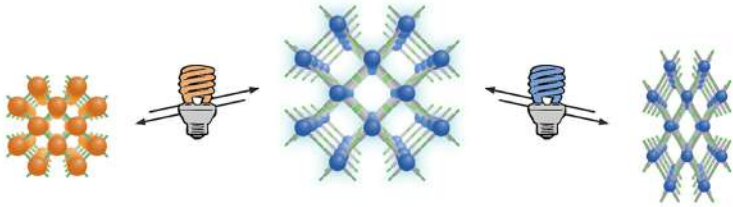
Nature has developed an intricate array of molecular machinery that powers nearly all aspects of metabolism, from protein synthesis to both cellular and macroscopic movement. Inspired by this complexity and versatility, a plethora of small-molecule artificial molecular machines and switches have been designed and synthesized.[1] Yet most of these synthetic counterparts have primarily been designed to operate and studied in diluted solutions, where the overwhelming Brownian motion precludes any cooperative action. Therefore, the development of practical strategies enabling spatial immobilization and organization of these dynamic small molecules as well as synchronization of their work remains a fundamental challenge.2

This talk will summarize our research on integrating artificial molecular machines and switches into extended porous frameworks. This approach not only facilitates the organization and immobilization of these functional molecules but also allows us to harness their collective motion within the material scaffold.[3,4] Our exploration covers a range of structures: beginning with rigid frameworks where molecular motion is restricted to individual molecules[5,6] and progressing to amorphous, flexible scaffolds that dynamically reorganize upon the isomerization of incorporated photoswitches.[7,8] Beyond these simple systems we venture into more complex architectures where multiple responsive units can operate independently, thus further extending the potential of these structures to exhibit intricate and adaptive behaviors.[9,10]



REFERENCES

1. K. Kinbara, T. Aida *Chem. Rev*. **2005**, *105*, 1377–1400.
2. A. Coskun, M. Banaszak, R. D. Astumian, J. F. Stoddart, B.A. Grzybowski *Chem. Soc. Rev.* **2012**, *41*, 19–30
3. L. Feng, R. D. Astumian, J. F. Stoddart *Nat. Rev. Chem.* **2022**, *6*, 705–725
4. S. Krause, B. L. Feringa *Nat. Rev. Chem.* **2020**, *4*, 550–562
5. W. Danowski, T. van Leeuwen, S. Abdolahzadeh, D. Roke, W. R. Browne, S. J. Wezenberg, B. L. Feringa *Nat. Nanotech. 2019*, *5*, 488-494
6. Y. Jiang, W. Danowski, B. L. Feringa, L. Heinke *Angew. Chem. Int. Ed.* **2023**, *62*, e202214202
7. F. Castiglioni, W. Danowski, J. Perego, F. K.-C. Leung, P. Sozzani, S. Bracco, S. J. Wezenberg, A. Comotti, B. L. Feringa *Nat. Chem.*, **2020**, *12*, 595-602
8. J. Sheng, J. Perego, W. Danowski, S. Bracco, S. Chen, X. Zhu, C. X. Bezuidenhout, S.Krause, W. R Browne, P. Sozzani, A. Comotti, B. L Feringa *Chem* **2023**, *9*, 2701-2716
9. J. Sheng, J. Perego, S. Bracco, P. Cieciórski, W. Danowski, A. Comotti, B. L. Feringa *Angew. Chem. Int. Ed.* **2024**, *63*, e202404878
10. J. Sheng, J. Perego, S. Bracco, P. Cieciórski, W. Danowski, A. Comotti, B. L. Feringa, *Proceedings of the National Academy of Sciences,* **2026, 5, e2520024123**

Switch, Stick, Solidify: Tuning Polymers with Light

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Externally controlling polymer properties with light offers powerful opportunities for adaptive materials. We recently demonstrated the first reversible light-induced liquid-to-solid transition in polysiloxanes functionalized with azobenzene–ureido pyrimidinone (Azo-UPy) units.[1] Photoisomerization switches the UPy motifs between intra- and intermolecular hydrogen bonding, generating supramolecular crosslinks that solidify the material and tune its mechanical properties. UV light irradiation also increases adhesion strength to glass sixfold, enabling light-controlled bonding and debonding.

To simplify this concept, we identified thiosemicarbazones as a new and readily accessible class of photoswitches featuring an integrated hydrogen-bonding thiourea group.[2] Their non-covalent interactions can be switched *on* and *off* using different wavelengths of light through photoisomerization. Substitution of the central chalcogen atom from oxygen to sulfur or selenium provides an additional handle to tune both their hydrogen-bonding properties and their interaction with light.[3] When incorporated into polymeric systems, these photoswitches enable light-induced modulation of mechanical properties and adhesion strength.[4]

Together, these results establish photoswitchable hydrogen bonding as a versatile molecular strategy for creating adaptive polymer materials whose macroscopic properties can be controlled on demand with light.

REFERENCES

[1] J. J. B. van der Tol, T. A. P. Engels, R. Cardinaels, G. Vantomme, E. W. Meijer, F. Eisenreich, "Photoswitchable Liquid-to-Solid Transition of Azobenzene-Decorated Polysiloxanes" *Adv. Funct. Mater.* **2023**, *33*, 2301246.

[2] B. Sentürk, B. Butschke, F. Eisenreich, "Thiosemicarbazones as versatile photoswitches with light-controllable supramolecular activity" *Chem. Sci.* **2025**, *16*, 3130–3140.

[3] B. Sentürk, S. Lekanne Deprez, W. Hennesen, C. Fonseca Guerra, F. Eisenreich, "Chalcogen Substitution Co-Tunes Photochromism and Hydrogen Bonding in Semicarbazone Photoswitches" *Chem. Sci.* **2026,** *17*, 14185–14193.

[4] B. Sentürk, F. Eisenreich, *unpublished results.*

Photoswitches for Solar Energy Storage and their Applications

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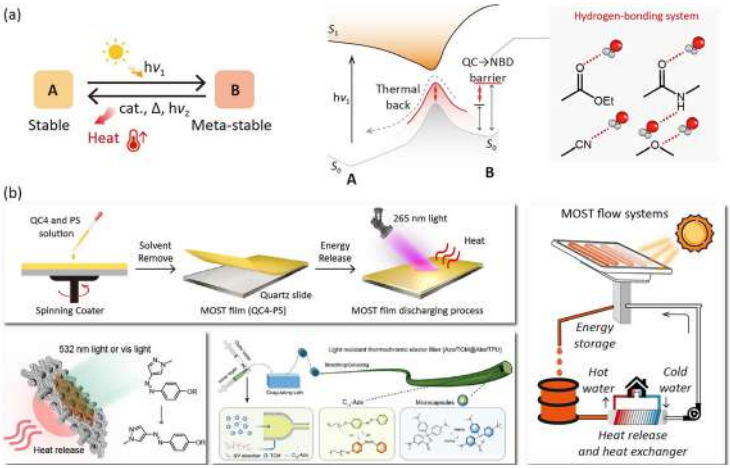
Molecular solar thermal (MOST) energy storage systems based on photoswitches have attracted considerable attention over the past decade as a promising strategy to address the global energy crisis through renewable energy utilization. These systems typically rely on photoswitching reactions, such as cycloadditions and electrocyclizations, as well as isomerization processes involving the interconversion of geometric (*E*/*Z*) or constitutional isomers. This presentation highlights recent developments in norbornadiene and Azo-based photoswitches as MOST materials, and their advantages in terms of energy density and storage stability.[1]



We focus on the realization of reversible two-way photoswitching processes and the modulation of thermal dynamics through hydrogen-bonding systems (Fig. 1a).[2-4] Furthermore, these MOST materials have been successfully integrated into both flow and solid-state platforms, including MOST fabrics, automated flow systems, and photothermal films (Fig. 1 b).[4,5] These advances provide a promising pathway toward the development of MOST materials with high energy storage capacity and enhanced robustness for thermal management applications.

REFERENCES

1. Wang, Z.; Erhart, P.; Li, T.; Zhang, Z.-Y.; Sampedro, D.; Hu, Z.; Wegner, H. A.; Brummel, O.; Libuda, J.; Nielsen, M. B.; Moth-Poulsen, K., Storing energy with molecular photoisomers. *Joule* **2021,** *5* (12), 3116-3136.
2. Fei, L.; Liasi, Z.; Elholm, J.; Hölzel, H.; Hansen, D.F.; Mikkelsen, K.V., Moth-Poulsen, K. Orchestrating Photoswitch Thermal Backconversion using Hydrogen Bonds to Reshape Energy Landscapes. *Nat. Commun.* **2026**. Accepted.
3. Fei, L.; Hölzel, H.; Wang, Z.; Hillers-Bendtsen, A. E.; Aslam, A. S.; Shamsabadi, M.; Tan, J.; Mikkelsen, K. V.; Wang, C.; Moth-Poulsen, K., Two-way photoswitching norbornadiene derivatives for solar energy storage. *Chem. Sci.* **2024,** *15* (43), 18179-18186.
4. Fei, L.; Yu, W.; Wu, Z.; Yin, Y.; Moth-Poulsen, K.; Wang, C., Optically Controlled Thermochromic Switching for Multi-Input Molecular Logic. *Angew. Chem. - Int. Ed.* **2022,** *61* (44), e202212483.
5. Fei, L.; Zhang, Z.-Y.; Tan, Y.; Ye, T.; Dong, D.; Yin, Y.; Li, T.; Wang, C., Efficient and Robust Molecular Solar Thermal Fabric for Personal Thermal Management. *Adv. Mater.* **2023,** *35* (16), 2209768.
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Rational Design of Molecular Motors for Single-Molecule Force Experiments

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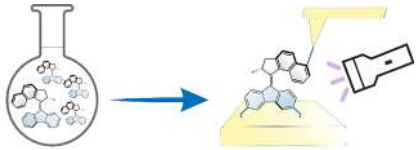
Over the past three decades, synthetic molecular motors have demonstrated the remarkable ability to convert energy inputs, such as light, chemical fuels or electricity, into directional mechanical motion. They have now become ubiquitous tools for controlling function and motion at the nanoscale, often amplified across length-scales to produce functional materials in the macroscopic world. However, quantifying the actual mechanical power generated by these nanoscopic machines has generally relied on theoretical calculations or extrapolations from macroscopic bulk phenomena. Until recently, the direct experimental measurement of the force generated by an individual artificial motor has remained a significant challenge.[1]

Here, we present the design and experimental study of molecular motors engineered specifically for such force measurements, and the probing of their motion at the single-molecule scale using scanning probe microscopy techniques, such as AFM-based single-molecule force spectroscopy (SMFS). In order to observe phenomena of such a small amplitude, the chemical structure of the studied motors had to be specifically engineered, allowing for a fine tuning of their rotation characteristics (length, sterics, rotation speed) and equipped with specific anchoring groups, enabling their study on surfaces.[2,3]

Our initial findings demonstrate the viability of this single-molecule approach, offering a direct quantitative readout of motor performance that can finally be benchmarked against existing theoretical calculations.



REFERENCES

1. D. R. S. Pooler, A. S. Lubbe, S. Crespi, B. L. Feringa, Designing light-driven rotary molecular motors. *Chem. Sci.* **2021**, *12*, 14964–14986.
2. X. Li, Y. Gisbert, M. Ledent, D. Sluysmans, G. Rapenne, C. Kammerer, A.-S. Duwez, Probing the free rotary oscillations around a single ruthenium atom in an organometallic complex. *Chem* **2026**, *12*.
3. M. Ledent, Y. Gisbert, D. Sluysmans, R. Astumian, B. Feringa, A.-S. Duwez, Interrogating a single light-driven rotary molecular motor with force. *Preprint*, 10.21203/rs.3.rs-6988620/v1.

Design and Synthesis of Novel Geometric Redox Switches

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Overcrowded alkenes are ubiquitous in a large range of light-driven molecular switches, machines and motors. In contrast, their actuation by electrochemical stimuli remains significantly unexplored even though this alternative energy input may be beneficial in various applications and enables orthogonal and complementary control over molecular switching states and properties. In this context, bisthioxanthylidene (BTX) has emerged as a powerful light- and redox-responsive alkene switch[1], which we have recently used in a range of proof-of-principle applications. This includes the development of multi-state ion receptors,[2,3] redox-switching of (anti)aromaticity[4] and redox--driven hydrogel actuators[5], highlighting the versatility of BTX. However, in order to enable a more wide-spread exploration of such redox-switches, their structural diversification is highly desirable, but remains challenging. Here, I will address this challenge and discuss the synthesis of a range of novel switches in which chemical or electrochemical redox is associated with significant and highly reversible changes in molecular geometry.[6-8] A particular focus will be the relationship between molecular structure/conformation and redox properties and how the latter can be rationally tuned.

REFERENCES

1. Browne, W. R.; Pollard, M. M.; de Lange, B.; Meetsma, A.; Feringa, B. L. Reversible three-state switching of luminescence: a new twist to electro-and photochromic behavior. *J. Am. Chem. Soc.* **2006**, *128*, 12412.
2. Hein, R.; Gisbert, Y.; Feringa B. L. Multi-state redox and light-driven switching of pseudorotaxanation and cation shuttling. *J. Am. Chem. Soc.* **2025***, 147,* 13649.
3. Hein, R.; Sidler, E.; Gisbert, Y.; Feringa B. L. Chiral induction and memory via supramolecular deracemization. *Angew. Chem. Int. Ed.* **2025***, 64,* e202510584.
4. Sidler, E.; Hein, R.; Doellerer, D; Feringa, B. L. Redox-switchable aromaticity in a helically extended indeno[2, 1-c]fluorene. *J. Am. Chem. Soc.* **2024**, *146*, 19168.
5. Weber, R. R.; Hein, R.; Ryabchun, A.; Gisbert, Y.; Romero, D. G.; Loi, M.A.; Feringa, B. L. Light--gated redox switching and actuation in polymer hydrogels. *Nat. Commun.* **2025**, *16*, 9106.
6. Hein, R.; Stindt, C.N.; Feringa B. L. Mix and match tuning of the conformational and multistate redox switching properties of an overcrowded alkene. *J. Am. Chem. Soc.* **2024**, *146*, 26275.
7. Mende, E.; Daniliuc, C.; Hein, R. Unpublished results.
8. Aßenmacher, D.; Sikora, B.; Daniliuc, C.; Hein, R. Unpublished results.

Transmission of autonomous motion through a chemically driven molecular gear

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In a molecular gear, rotation about one bond is coupled with simultaneous rotation about another. However, most reported molecular gears rotate randomly: the motion of the geared system is *correlated*, but it is not *directional*. In this work, we describe a tightly interlocked molecular gear containing two axes in which rotation about a C–C bond is continually and autonomously driven in a directional manner by a biocatalytic cyclic redox reaction network. The designed structure of the gear ensures that redox-fuelled anticlockwise rotation of the C–C axis is transmitted reliably to a second, C–N axis, which rotates clockwise as a result. This system constitutes the first example of chemically driven directional rotation being transmitted from one axis to another, with near-complete gear fidelity.

REFERENCES

1. Theo H. N. Bulless, Michael G. Howlett, Nicholas T. O'Donoghue, Matej Zabka, Beatrice S. L. Collins, and Jonathan Clayden. Transmission of autonomous redox-driven directional bond rotation through a molecular gear. *ChemRXiv.* **2025**, 10.26434/chemrxiv-2025-hmnb4.

Atropisomer Mechanochemistry – Force Triggered Conversion of Atropisomer Stereochemistry

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Atropisomers are a subclass of conformers which can be isolated as separate chemical species and which arise from restricted rotation about a single bond. The atropisomerism is a chiral phenomenon that plays a critical role in various fields of science, including medicinal chemistry, catalysis, and materials science. Here we describe a new mechanochemistry pathway, termed "atropisomer mechanochemistry," where mechanical force drives diastereomerization of atropisomers via axial rotation (atropisomerization). Although this process involves only axial rotation, the resulting diastereomeric conversion formally constitutes a chemical reaction that alters chemical reactivity, thereby expanding mechanochemistry beyond the traditional bond-forming/breaking paradigm while providing new insights into the important chiral phenomenon of atropisomerism. As an example, a congested parallel diarylethene mechanophore in the (Ra, Sa)-configuration with mirror symmetry is atropisomerized to its antiparallel diastereomers with C2 symmetry under ultrasound-induced force field. The resulting stereochemistry-converted material gains symmetry--allowed reactivity toward conrotatory photocyclization, enabling the colorimetric visualization of a material's mechanical history. Integrating these mechanosensitive atropisomers in organic and polymeric materials has the potential to create safer and 'smarter' plastics that autonomously monitor and report early mechanical damage, enhancing sustainability by reducing the need for unnecessary preventive replacement of components. Moreover, the record-setting sub-200-pN mechanochemical sensitivity achieved in these atropisomer mechanophores could enable the study of previously unobservable nanoscale mechanical behaviors, holding promise for advancing our understanding in polymer physics, materials science, and mechanobiology.

REFERENCES

1. Xuancheng Fu, Boyu Zhu, Xiaoran Hu* Journal of the American Chemical Society 2023, 145, 15668-15673.
2. Cijun Zhang, Tatiana B. Kouznetsova, Boyu Zhu, Liam Sweeney, Max Lancer, Ivan Gitsov, Stephen L. Craig, Xiaoran Hu* Journal of the American Chemical Society 2025, 147, 2502–2509
3. Cijun Zhang, Xuancheng Fu, Xiaoran Hu* Synlett 2024, 35, 1601-1608.
4. Cijun Zhang, Liam Sweeney, Boyu Zhu, Ivan Gitsov, Xiaoran Hu* Preprint: doi.org/10.26434/chemrxiv.15004575/v1
5. Shakkeeb Thazhathethil, Sameeha Yoosaf, Cijun Zhang, Ramarani Sethy, Jared Chrissley, Quinn Qiao, John D. Chisholm, Weiwei Zheng, Xiaoran Hu* Preprint: doi.org/10.26434/chemrxiv.15004461/v1

Light-responsive dynamic covalent systems: out-of-equilibrium states, switching and catalysis

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Dynamic covalent bonds allow structural adaptation of molecules, thus creating a network of intertwined reactions and constituting a whole chemical system. Such adaptations can occur either spontaneously or can be driven by external stimuli. The range of such stimuli includes thermal, chemical, electrochemical or photochemical ones. Light is one of the most powerful stimuli, largely exceeding thermal excitation and can deliver out-of-equilibrium states corresponding to temperatures up to 500 °C, which is far beyond the decomposition temperatures of organic molecules.1 Light can also induce intramolecular structural adaptation, such as in the case of photoswitching. In the particular case of acylhydrazone photoswitches featuring a thiophene ring substituted in position 2, the photoswitching is associated not only with a geometrical change, but surprisingly also by switching of the electronic ground state from closed-shell singlet to stable open-shell triplet state. This behavior is also observed in solid state and the diradical character of the triplet isomer can be used as an initiator/catalyst in common radical substitution reactions.2
The strong out-of-equilibrium shift of photoexcited states and the structural adaptability allows us to expand the concept even further. We have prepared and studied a series of deazaoxaflavins (DAOFs), covalently dynamic analogues of known flavin photocatalysts. DAOFs are potent photoredox catalysts of benchmark reactions and their synthesis is done by two reversible condensation reactions. Upon mixing, dynamic reaction network is established with various concentrations of all species. When photocatalytic conditions are installed, the species able to catalyze is involved in the catalytic cycle and thus removed from the equilibrium. The system responds by producing more of the catalyst due to Le Chatelier principle. As a result, the catalyst formation is driven by its photocatalytic function, a phenomenon of intriguing importance in the field of catalysis.[3]

This work was funded by the Czech Science Foundation grant JuniorSTAR 22-11299M.

REFERENCES

1. Robson, H.; Kovaříček, P. *J. Photochem. Photobiol. A Chem*. **2025**, *468*, 116490.
2. Šetek, M.; Guerra, V. L. P.; Robson, H.; Geleverya, A. O.; Maxa, O.; Lamancová, A.; Eigner, V.; Nachtigallová, D.; Tarábek, J.; Kovaříček, P. *J. Mater. Chem. C* **2025**, *13*, 9520-9526.
3. Křížová, K.; Ismail, R.; Nguyen, T. A.; Bříza, M.; Geleverya, A. O.; Ciotta, C.; Guerra, V. L. P.; Kovaříček, P. *J. Org. Chem.* **2025**, *90*, 14039–14044.

Spin-State Photoswitching Drives Dual Rotors

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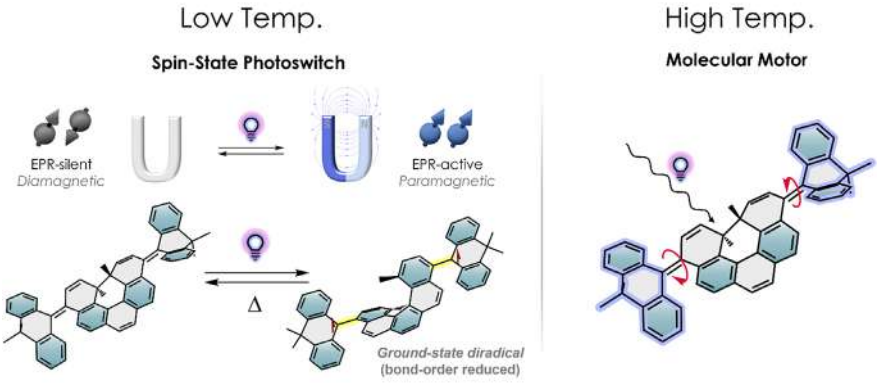
Light-driven molecular motors operate through photochemical *E/Z* isomerization (PEZ) followed by thermal helix inversion (THI).[1] Since the rise of molecular motor science, the fundamental process of PEZ via an excited state species and a torsional motion remained largely unchanged.[2] Here we report a [5]helicene-based molecular machine in which spin-state photoswitching generates a metastable ground-state diradical that replaces the highly transient bond-order reduction of conventional motors.[3] Dependent on the temperature, the system behaves like an organic spin--state photoswitch below 95 K,[4,6] or a molecular motor above 135 K. The long-lived diradical species at low temperature enables direct spectroscopic observation of the PEZ intermediate and establishes an alternative pathway for molecular rotation. Combined with a dual-rotor architecture in which a single excitation event generates two localized radical centers — one at each rotational axle — these findings introduce ground-state bond-order engineering as a new design principle for light-driven molecular motors.



REFERENCES

1. Koumura, N.; Zijlstra, R. W.; van Delden, R. A.; Harada, N.; Feringa, B. L. Light-driven monodirectional molecular rotor. *Nature* **1999**, *401*, 152–155.
2. Costil, R.; Holzheimer, M.; Crespi, S.; Simeth, N. A.; Feringa, B. L. Directing Coupled Motion with Light: A Key Step Toward Machine-Like Function. *Chem. Rev.* **2021**, *121*, 13213–13237.
3. *unpublished result.*
4. Günther, K.; Grabicki, N.; Battistella, B.; Grubert, L.; Dumele, O. An All-Organic Photochemical Magnetic Switch with Bistable Spin States *J. Am. Chem. Soc.* **2022**, *144*, 8707–8716.
5. Schlecht, J.; Lohmiller, T.; Thielert, P.; Douglas, C.; Gather, M.; Richert, S.; Dumele, O. *Angew. Chem. Int. Ed.* **2025**, *64*, e202515144.
6. Miyamura, T.; Schlecht, J.; Dumele, O. *Angew. Chem. Int. Ed.* **2025**, *64*, e202512691.

Light-Enhanced Chloride Transport by Thiourea-Appended Molecular Motor

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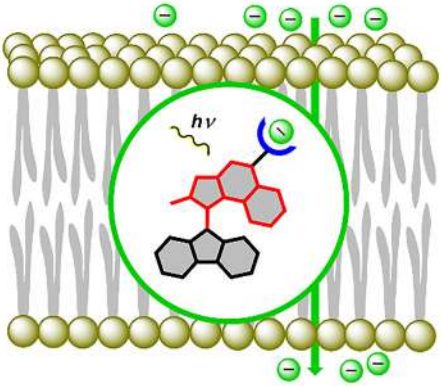
The regulation of solute transport across lipid bilayer membranes is central to many biological processes and is typically mediated by protein transporters that dynamically respond to stimuli. The development of artificial systems that emulate such responsive behavior remains a major challenge. Here, we show enhancement of chloride transport under light irradiation using a Feringa-type molecular rotary motor connected to a thiourea anion-binding motif. The photo-generated metastable state of the motor-based transporter exhibits up to 85% higher activity relative to its dark state, where the transport process itself is gradient-driven (passive transport). Continuous light energy input is required to sustain the more active metastable non-equilibrium state. This work demonstrates application of light-driven molecular motor to facilitate and regulate transmembrane anion transport. Further, our studies will be of guidance in the development of molecular motor-based strategies that will advance artificial transporters towards dynamic light-responsive systems with spatiotemporally controllable activity.



REFERENCES

1. Gale, P. A.; Davis, J. T.; Quesada, R. *Anion transport and supramolecular medicinal chemistry.* Chem. Soc. Rev. 2017, **46,** 2497-2519.
2. Koumura, N.; Geertsema, E. M.; Gelder M, B.; Meetsma A; Feringa, B. L. *Second Generation Light-Driven Molecular Motors. Unidirectional Rotation Controlled by a Single Stereogenic Center with Near-Perfect Photoequilibria and Acceleration of the Speed of Rotation by Structural Modification***.** J. Am. Chem. Soc., 2002, **124,** 5037-5051.

From Small Machines to Complex Assemblies

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The design and synthesis of molecular machines, notably motors, have evolved considerably in recent years.[1-4] One fundamental challenge is now to assemble these discrete units into higher-order architectures capable of performing collective work, as exemplified in biology by ATP synthase. We are currently developing elementary machine units—switches and motors—with the aim of integrating them into complex assemblies and devices with applications in endergonic synthesis,[5] artificial muscles, and smart materials, where nanoscale mechanical motion translates into programmable material behaviour.

REFERENCES

1. Koumura, N.; Zijlstra, R. W. J.; van Delden, R. A.; Harada, N.; Feringa, B. L. Light-Driven Monodirectional Molecular Rotor. *Nature* **1999**, *401*, 152–155.
2. Borsley, S.; Kreidt, E.; Leigh, D. A.; Roberts, B. M. W. Autonomous Fuelled Directional Rotation about a Covalent Single Bond. *Nature* **2022**, *604*, 80–85.
3. Berreur, J.; Watts, O. F. B.; Bulless, T. H. N.; O'Donoghue, N. T.; Del Olmo, M.; Winter, A. J.; Clayden, J.; Collins, B. S. L. Redox-Powered Autonomous Directional C–C Bond Rotation under Enzyme Control. *Nature* **2025**, *644*, 96–101.
4. Wang, P. -L.; Olivieri, E.; Borsley, S.; Whitehead, G. F. S.; Hasija, A.; Leigh, D. A. A Catalysis-Driven Dual Molecular Motor. *J. Am. Chem. Soc.* **2025**, *147*, 10690–10697.
5. Olivieri, E.; Gallagher, J. M.; Betts, A.; Mrad, T. W.; Leigh, D. A. Endergonic Synthesis Driven by Chemical Fuelling. *Nat. Synth.* **2024**, *3*, 707–714.

Do Light-Driven Motors Really Work Differently? Kinetic Asymmetry In Photochemistry

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Autonomous molecular motors are commonly divided into two mechanistic families. Chemically fuelled motors are understood as Brownian information ratchets, in which directionality arises from kinetic asymmetry rather than from energy differences between intermediates. Light-driven rotary motors, by contrast, are usually described in energetic terms — an uphill photoisomerization followed by a downhill, effectively irreversible thermal step — a picture that has suggested they operate by a fundamentally different, power-stroke-like mechanism. Here we revisit this distinction by analysing photo-driven motors at the level of their chemical reaction networks. Starting from elementary vibronic transitions and coarse-graining systematically to reactions between ground--state species, we find that the constraint linking kinetics to thermodynamics is preserved for the effective photoisomerization steps, just as it is for ordinary thermal reactions. A direct consequence is that, for an autonomous ratchet under constant illumination, the equilibrium constants of the thermal isomerization steps do not enter the expression for directionality: there is no energy--ratchet contribution, and net motion requires differences in the fluxes of the light-harnessing photoisomerization reactions. In other words, autonomous light-driven and catalysis-driven motors share the same information-ratchet principle. We trace the prevailing alternative view to a natural approximation of the ratcheting constant that omits small but non-independent thermal fluxes, obscuring this constraint. The unification extends kinetic-asymmetry thinking to photochemistry and suggests design should target differences in quantum yields, absorption and fluxes of the free-energy-harnessing steps.

REFERENCES

1. Avanzini, F.; Esposito, M.; Penocchio, E. Coarse Graining Photo-Isomerization Reactions: Thermodynamic Consistency and Implications for Molecular Ratchets. *J. Chem. Phys.* **2025**, *163*, 134122.
2. Penocchio, E.; Rao, R.; Esposito, M. Nonequilibrium Thermodynamics of Light-Induced Reactions. *J. Chem. Phys.* **2021**, *155*, 114101.

Machinery of multiple rotors and switches in porous responsive architectures

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The precise spatial arrangement of dynamic building blocks with defined geometry and topology is accomplished in low-density framework materials, including Metal-Organic Frameworks (MOFs) and Porous Aromatic Frameworks (PAFs). We succeeded in incorporating ultra-fast bicyclo[1. 1. 1]pentane (BCP) molecular rotors and bipyridine-based co-ligands into pillared-layer MOFs, generating a 3D array of orthogonal rotors that operate in a concerted cascade dynamics.[1] Indeed, the BCP rotors generate co-rotating pairs, resulting in geared molecular rotors with low rotational energy barriers (24 cal·mol^{-1}) due to synchronized motion. The introduction of azobipyridine, endowed with pedal-like motion, further increases the complexity of the solid-state machinery.[2] Pressurized CO_2 decreases BCP dynamics through incremental site occupation, while I_2 uptake drives a dramatic structural rearrangement and enhances BCP mobility. In fluorinated MOFs containing rotating geminal fluorine atoms benchmark mobility of correlated dipolar rotors with an almost negligible activation energy (E_a = 17 cal·mol^{-1}) was shown, suggesting potential for electric-field-responsive porous materials.[3] Light-responsive Porous Switchable Frameworks (PSFs) based on bistable chiroptical overcrowded alkenes inserted in the backbone of the frameworks display reversible porosity and gas sorption modulation by light and heat, mimicking a sponge-like behavior.[4] Remarkably, an all-visible-light-responsive porous framework demonstrates CO_2 uptake modulation under visible light irradiation, thereby reducing the energy penalty for carbon capture and recovery.[5] Overall, integrating the motion of dynamic elements with global framework flexibility provides novel multi-responsive materials, suitable for applications such as gas sorption modulation, controlled guest uptake and release, complex dielectric response and switchable mechanical behavior.

REFERENCES

1. Perego, J. *et al.* Cascade Dynamics of Multiple Molecular Rotors in a MOF: Benchmark Mobility at a Few Kelvins and Dynamics Control by CO2. *J. Am. Chem. Soc.* **2021**, *143*, 33, 13082-13090.
2. Perego, J. *et al.* Solid state machinery of multiple dynamic elements in a metal–organic framework *Angew. Chem. Int. Ed.* **2024**, *63*, 10, e202317094.
3. Perego, J. *et al.* Benchmark Dynamics of Dipolar Molecular Rotors in Fluorinated Metal-Organic Frameworks. *Angew. Chem. Int. Ed.* **2023**, *62*, 5, e202215893.
4. Sheng, J. *et al.* Construction of a three-state responsive framework from a bistable photoswitch. *Chem* **2023**, *9*, 2701-2716.
5. Sheng, J. *et al.* All-visible-light-responsive porous aromatic frameworks manipulate CO_2 uptake by reversible bulk isomerization of azobenzene pendants. *PNAS* **2026**, *123*, 5, e2520024123.

Biocompatible photochromic systems: gels, cages, and photopharmacology

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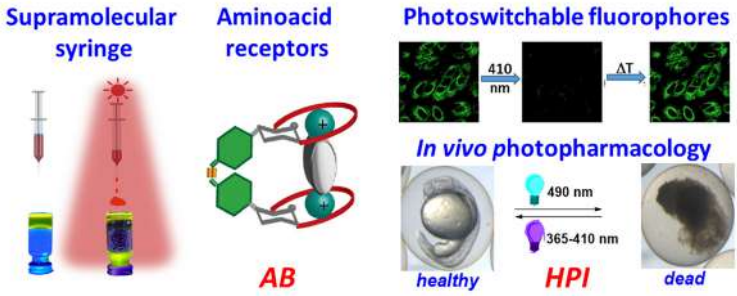
Our group investigates photoswitching with visible light, often in aqueous media, to photomodulate biological systems at diverse levels of complexity. We adapt established azobenzene systems (AB) to create biocompatible materials and molecular architectures, such as supramolecular hydrogels,[1] aminoacid receptors,[2] or molecular cages[3] - triggered with red or green light, and operational in aqueous media. We also used ABs to reversibly assemble protein nanocages.



We also explore applications of peptide-derived photoswitches – hemipiperazines (HPI) based on the Z-E-photoisomerization of arylidene-substituted 2,5-diketopiperazines – discovered in our group in 2022.[4] We used HPI-containing plinabulin (a low-nM antimitotic agent which undergoes in vitro activity photomodulation by two orders of magnitude[4]) to photocontrol development of zebrafish embryos.[5] We also shown that Indolo-HPIs can work as photoswitchable fluorophores in living cells.[6]

REFERENCES

1. Leistner, A.-L.; Most, M.M.; Pianowski, Z. Molecular syringe for cargo photorelease - red--light-triggered supramolecular hydrogel *Chem. Eur. J.* **2023,** *e202302295* DOI: 10.1002/chem.202302295
2. Most M.M., Boll L.B., Gödtel P., Pianowski Z.L., Lewandowski B. Glucose-derived receptors for photocontrolled binding of amino acid esters in water *Commun. Chem*. **2025**, *8,* 50. DOI: 10.1038/s42004-025-01445-x
3. Schäfer, V.; Seliwjorstow, A.; Fuhr, O.; Pianowski, Z.L. Dynamically assembled photochromic cages operational in water with visible light *Nat. Commun.* **2026**, *17,* 2488; DOI: 10.1038/s41467-026-70406-2
4. Kirchner, S.; Leistner, A.-L.; Gödtel, P.; Seliwjorstow, A.; Weber, S.; Karcher, J.; Nieger, M.; Pianowski, Z. Hemipiperazines as peptide-derived molecular photoswitches with low-nanomolar cytotoxicity. *Nat. Commun.* **2022**, *13* (1), 6066. DOI: 10.1038/s41467-022-33750-7.
5. Seliwjorstow, A.; Takamiya, M.; Rastegar, S.; Pianowski, Z. Reversible Influence of Hemipiperazine Photochromism on the Early Development of Zebrafish Embryo. *ChemBioChem* **2024**, *25 (8),* e202400143. DOI: 10.1002/cbic.202400143
6. Gödtel, P.; Rösch, A.; Kirchner, S.; Elbuga-Ilica, R.; Seliwjorstow, A.; Fuhr, O.; Schepers, U.; Pianowski, Z. Photoswitchable Fluorescence of Peptide-Based Hemipiperazines Inside of Living Cells. *J. Am. Chem. Soc.* **2025**, *147* (30), 26652-26662. DOI: 10.1021/jacs.5c07013.

A Brownian approach to transport

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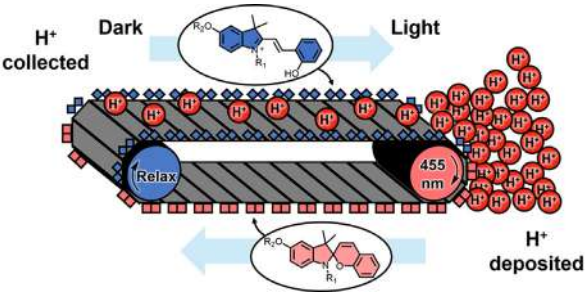
Chemical gradients spontaneously dissipate. Over time, concentrations equilibrate and conditions homogenise. To maintain a gradient, as biological systems do, a supply of energy is needed to drive the chemical concentrations out of equilibrium and then sustain the nonequilibrium state. From work on molecular motor molecules, we now know how to use Brownian ratchet mechanism to perform such tasks.[1] Kinetic selection during (photo-)chemically driven reactions creates population imbalances, allowing directional motion and other nonequilibrium behaviours to be performed while the populations strive to reequilibrate.
In this talk, I will show how ratchet mechanisms can be adapted to generate and sustain nonequilibrium concentration gradients. Merocyanine photoacids act as the key component for transducing light energy into directional diffusion of protons and hence an unbalanced pH. By continuous cycling of photoacid carrying protons from the dark into the light, pH patterns can be sustained in gels for a timescale of hours: far above the approximately 15 minutes it takes to equilibrate the pH within the same gel with a non-photoresponsive acid. This opens a path not only to the creation of persistent or responsive pH patterns, but also for directional and targeted proton transport.



REFERENCES

1. Borsley, S.; Leigh, D. A.; Roberts, B. M. W. Molecular ratchets and kinetic asymmetry: giving chemistry direction. *Angew. Chem. Int. Ed.* **2024**, *63*, e202400495.

Engineering Multistate Photoswitches For Molecular Solar Thermal (Most) Energy Storage And Beyond

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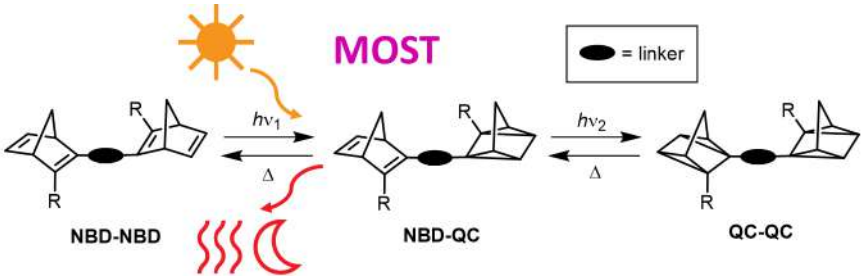
The ever-increasing global demand for clean energy supply has driven extensive research into renewable energy technologies. Molecular solar thermal energy storage (MOST) systems offer a promising route to emission-free energy storage by using molecular photoswitches that can reversibly store solar energy in chemical bonds.[1] Norbornadiene (NBD) is a promising photoswitch that converts to the highly strained photoisomer quadricyclane (QC) upon irradiation, exhibiting a high energy storage density of up to 1 MJ kg^{-1}. In addition to energy storage density, to optimise NBDs for use in MOST devices, several key parameters must be balanced, including photoconversion, heat release, storage lifetime, solubility and synthesis scalability. Multichromophoric systems incorporating two or more photochromic units offer additional functionality over monosubstituted analogues through access to multiple switching states and extended conjugation, often resulting in red-shifted absorption profiles and hence a better overlap with the solar spectrum.[2,3] Here we present a series of *ortho*- and *para*-functionalised NBD dimers for MOST applications.[4] In addition to photoisomerisation, some of the molecules are fluorescent. Their optical behaviour can be modulated through molecular structure and solvent environment, enabling selective optimisation towards either fluorescence-based applications or efficient energy storage and release. Device integration and catalytic heat release provide insight into the requirements for translating molecular photoswitches towards practical MOST applications.



REFERENCES

1. J. Orrego-Hernández, A. Dreos, K. Moth-Poulsen, *Acc. Chem. Res.,* **2020**, *53*, 1478–1487.
2. R. J. Salthouse, K. Moth-Poulsen, *J. Mater. Chem. A.* **2024**, *12*, 3180-3208.
3. R. Schulte, S. Afflerbach, T. Paululat and H. Ihmels, *Angew. Chem. Int. Ed*., **2023**, e202309544.
4. R. J. Salthouse, J. L. Elholm, I. Cortellazzi, H. Hölzel, P. Ferreira, L. Fernandez, M. K. Etherington, K. Moth-Poulsen, *Angew. Chem. Int. Ed.*, **2025**, *138*, e16629.

Chemical Vapor Deposited Functional Polymer Thin Films for Light-Driven Actuation and Molecular Machines

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Functional polymer thin films are of great interest as platforms for incorporating photoswitchable molecules and translating molecular-scale transformations into macroscopic motion. The increasing demand for miniaturized and advanced polymer-based systems requires precise control over film thickness, composition, and functionality. Solvent-free initiated chemical vapor deposition (iCVD) meets these demands by circumventing dewetting and surface tension effects encountered in conventional solution-based polymer thin film fabrication.[1,2] The iCVD process enables conformal polymer coatings with nanometer-scale thickness on large-area substrates and complex three-dimensional geometries, as well as freestanding polymer films fabricated via sacrificial template growth. This talk demonstrates the capability of iCVD to fabricate photoresponsive copolymer actuators exhibiting large-amplitude macroscopic actuation.[3,4,5] In addition, permanently polarized (electret) polymer surfaces are presented as versatile platforms for molecular machine research, providing a well-defined, persistent electrostatic field for studying and controlling molecular motion and interfacial interactions.[6]

REFERENCES

1. Schröder, S.; Polonskyi, O.; Strunskus, T.; Faupel, F. Nanoscale gradient copolymer films via single-step deposition from the vapor phase. *Mater. Today* **2020**, *37*, 35-42.
2. Barg, I.; Kohlmann, N.; Rasch, F.; Strunskus, T.; Adelung, R.; Kienle, L.; Faupel, F.; Schröder, S.**;** Schütt, F. Strain-Invariant, Highly Water Stable All-Organic Soft Conductors Based on Ultralight Multi-Layered Foam-Like Framework Structures. *Adv. Funct. Mater.* **2023**, *33*, 2212688.
3. Burk, M. H.; Schröder, S.; Moormann, W.; Langbehn, D.; Strunskus, T.; Rehders, S.; Herges, R.; Faupel, F. Fabrication of Diazocine-Based Photochromic Organic Thin Films via Initiated Chemical Vapor Deposition. *Macromolecules* **2020**, *53*, 1164-1170.
4. Burk, M. H.; Langbehn, D.; Hernández Rodríguez, G.; Reichstein, W.; Drewes, J.; Schröder, S.; Rehders, S.; Strunskus, T.; Herges, R.; Faupel, F. Synthesis and Investigation of a Photoswitchable Copolymer Deposited via Initiated Chemical Vapor Deposition for Application in Organic Smart Surfaces. *ACS Appl. Polym. Mater.* **2021**, *3*, 1445-1456.
5. Burk, M. H.; Hugenbusch, D.; Arndt, C.; Pott, L.; Hauck, M.; Drewes, J.; Rehders, S.; Strunskus, T.; Hartig, T.; Selhuber-Unkel, C.; Adelung, R.; Schütt, F.; Herges, R.; Faupel, F.; Schröder, S. A freestanding photoswitchable aero-polymer with an incorporated bridged azobenzene: 3D structure, photoinduced motion, biocompatibility and potential application as photomechanical cell scaffold. *ChemRxiv* **2023**. *DOI: 10.26434/chemrxiv-2023-15rbd.*
6. Schröder, S.; Hartig, T.; Clausen, K. U.; Strunskus, T.; Faupel, F. Tunable polytetrafluoroethylene electret films with extraordinary charge stability synthesized by initiated chemical vapor deposition for organic electronics applications. *Sci. Rep.* **2019**, *9*, 2237.

The Nonadiabatic Nature of the Substituent Effects in Azobenzene

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Molecular photoswitches are molecules that can be converted between two configurational isomeric states by means of an external stimulus, in this case, light.[1] One of the most studied photoswitches is azobenzene, which (photo)isomerises about a N=N double bond. The suitability of an azobenzene towards a particular application depends heavily on the thermal lifetime (τ) of the metastable Z-isomer. Hence, understanding the mechanisms of isomerisation is imperative. Since the discovery of azobenzenes' photoisomerisation nearly a century ago,[2] the Z→-E thermal isomerisation mechanism has been scrutinised, with the main discussion focusing on inversion and rotation about the central N=N double bond. Despite extensive efforts, the experimentally observed negative activation entropy values for azobenzene could never be reconciled with either of those two mechanisms. This so-called "entropy puzzle" for unsubstituted azobenzene was solved by applying a non-adiabatic rotation mechanism that accounts for the negative sign of the entropy.[3] The discussion of these three mechanisms has been proposed to account for the nonlinear substituent dependence of the thermal reaction rate of para-substituted azobenzenes. In this work, we combine systematic kinetic analysis with temperature-dependent Eyring and isokinetic analysis to experimentally evaluate the origin of this behaviour. A series of para-substituted azobenzenes exhibits uniformly negative entropies of activation, suggesting a single nonadiabatic rotational mechanism across the series. We found that the characteristic "V-shaped" Hammett correlation of azobenzenes arises from an inadequacy of the Hammett (σ_p) parameter to describe the stabilisation of the open-shell, diradicaloid species involved in the nonadiabatic pathway. Employing the Creary ($\sigma\cdot$) radical parameter restores the linearity and confirms that both electron-donating and electron-withdrawing substituents increase the reaction rate and stabilise the diradicaloid species.

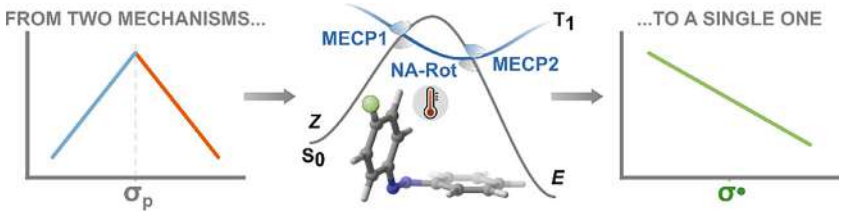

Figure 1. The thermal *Z→E* isomerisation of *para*-substituted azobenzenes proceeds through a single nonadiabatic rotational pathway. The classic "bell-shaped" Hammett plot is a parameter artefact, not a reflection of a mechanistic change, exposing the limits of single-reference DFT and establishing activation entropy as a key diagnostic for azo photoswitch design.

REFERENCES

1. Feringa, B.L.; Browne, W.R. *Molecular Switches*, 2011, Vol. 1 & 2, Wiley-VCH GmbH, Weinheim, Germany
2. Hartley, G.S. The cis-form of azobenzene and the velocity of the thermal cis→trans-conversion of azobenzene and some derivatives. *J. Chem. Soc.*, **1938**, 633-642.
3. Reimann, M.; Teichmann, E.; Hecht, S.; Kaupp, M. Solving the Azobenzene Entropy Puzzle: Direct Evidence for Multi-State Reactivity. *J. Phys. Lett.*, **2022**, *13*, 10882-10888.

Functional Single-Molecule Super-Resolution Microscopy with Switchable Fluorescent Molecules

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Abstract: Single-molecule localization microscopy (SMLM) permits subdiffraction optical imaging. It relies on molecular switches that undergo stochastic, reversible transitions between fluorescent "on" and non-fluorescent "off" states. This dynamic behavior is achieved either through photoswitching or transient binding, where the latter probes the reversible supramolecular association and dissociation to generate stochastic blinking. Building on both strategies, we have developed a suite of switchable fluorophores for functional and multiplexed super-resolution microscopy (SRM) to report nanoscale physicochemical information via single-molecule fluorescence spectroscopic imaging.

Spanning these two design paradigms, our laboratory has engineered three primary fluorophore platforms: (1) reversibly photoswitchable fluorescent hydrazone probes, tuned via electron--donating groups to enhance photoswitching contrast and photostability for live-cell super--resolution membrane imaging; (2) solvatochromic, far-red-emitting BODIPY dyes featuring polarity-independent absorption, where a conjugated zwitterionic lipid drives transient-binding switching via supramolecular hydrophobic interactions for selective plasma membrane targeting and nanoscale polarity mapping while maintaining a scaffold amenable to engineered photoswitching; and (3) spectroscopic DNA-PAINT (sDNA-PAINT), which extends transient DNA hybridization to spectroscopic SMLM for simultaneous 4-color multiplexed imaging across spectrally overlapping dyes.

To support these platforms, we developed deep-learning frameworks to denoise and classify single-molecule spectral signatures, improving the discrimination of switch states and dye identities at the single-molecule level. Using this integrated approach, we successfully map cholesterol--induced nanoscale membrane polarity changes in live mammalian cells with a localization precision of sub-20 nm, and achieve accurate four-color multiplexed subcellular imaging in a single acquisition via sDNA-PAINT.

REFERENCES

(1) Liu, Y.; Gong, X.; Yoder, B.; Gluck, J. M.; Vinueza, N. R.; Liu, X.; Zhang, Y. Solvatochromic BODIPYs with Polarity-Independent Absorption for Functional Super-resolution Imaging of Live Cell Membranes. Chem. Biomed. Imaging 2026, 4 (4), 527–532.
(2) Mao, H.; Liu, Y.; Venkataraman, O. K.; Shahid, M.A.; Laplante, C.; Xu, D.; Song, K.-H.; Zhang, Y. Framework for Accurate Single-Molecule Spectroscopic Imaging Analyses Using Monte Carlo Simulation and Deep Learning. Anal. Chem. 2025, 97 (30), 16250–16258.
(3) Shahid, M.A.; Das, S. C.; Patel, K.; Gong, X.; Mao, H.; Miller, D. A.; Zhang, Y. Spectroscopic DNA--PAINT for Simultaneous Multiplexed Super-Resolution Microscopy. Nano Lett. 2026, DOI: 10.1021/acs.nanolett.6c01802.
(4) Qi, Q.; Liu, Y.; Puranik, V.; Patra, S.; Svindrych, Z.; Gong, X.; She, Z.; Zhang, Y.; Aprahamian, I. Photoswitchable Fluorescent Hydrazone for Super-Resolution Cell Membrane Imaging. J. Am. Chem. Soc. 2025, 147 (19), 16404–16411.

List of posters

	LAST NAME AND FIRST NAME	TITUL
P01	Bastien Guillaume	TRIPTYCENE-BASED TRIPODAL MOLECULAR PLATFORMS
P02	Baxter Willow	CHEMICALLY FUELLED ACTIVE TRANSPORT CASCADES IN LARGE UNILAMELLAR VESICLES
P03	Craciunescu Tudor	THEORETICAL AND EXPERIMENTAL INVESTIGATION OF ENERGY STORAGE IN PHOTO-SWITCHABLE MOLECULES FOR SOLAR THERMAL STORAGE
P04	Fei Li	TRIPTYCENE-BASED TRIPODAL MOLECULAR PLATFORMS FOR PHOTOSWITCHABLE LANGMUIR-BLODGETT FILMS
P05	Noakes Martha	LIGHT ISN'T MAGIC: CHEMICALLY VERSUS PHOTOCHEMICALLY DRIVEN ISOMERISATION OF A DOUBLE BOND
P06	Pedük Ilayda	MOTOR-BASED DNA-BINDER WITH PHOTOCONTROLLED AFFINITY
P07	Qian Chen	MECHANOCHEMISTRY OF ARTIFICIAL MOLECULAR MOTORS
P08	Severa Lukáš	LIGHT-GATED CONTROL OF BROWNIAN ROTATION BY A MOLECULAR MOTOR
P09	Xue Haoyun	MECHANICAL REGULATION OF WATER-SOLUBLE MOLECULAR MOTORS IN BIOLOGICAL MEMBRANES
P10	Miyamura Takuma	SPIN-STATE PHOTOSWITCHING DRIVES DUAL ROTORS

Posters

P01

Triptycene-Based Tripodal Molecular Platforms for Photoswitchable Langmuir-Blodgett Films

Guillaume Bastien,[a] Carina Santos Hurtado,[a] Eva Kaletová,[a] Katarina Majerová Varga,[a] Milan Mašát,[a] Lukáš Severa,[a] Martin Škuta,[a] Jiří Rybáček,[a] Veronika Šolínová,[a] Václav Kašička,[a] Ivana Císařová,[b] Zdeněk Bastl,[c] Jiří Kaleta[a]

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Surface-mounted molecular devices are a unique class of stimuli-responsive smart materials that continue to attract significant scientific interest due to their broad range of potential applications. In recent years, our group has focused on the development of photoswitchable surfaces based on Langmuir–Blodgett films. The first generation of these systems[1] relied on triptycene for self-assembly and a single carboxylic acid group for surface anchoring. Although functional, these monopodal systems suffer from several drawbacks, including tilting towards the surface and the high flexibility of their long, rod-shaped molecular structures.

To overcome these limitations, we developed a second generation of molecular platforms based on shorter tripodal architectures.[2] In this approach, triptycene derivatives are functionalized with three anchoring groups, while the molecular length is minimized to reduce excessive flexibility and improve surface organization. This tripodal platform can be further functionalized with various molecular photoswitches and motors through Sonogashira coupling reactions.

After confirming that the photoactive units remained operational in solution by NMR and UV–vis spectroscopy, Langmuir–Blodgett films were prepared and deposited onto various substrates.[3] The resulting films were characterized in terms of their molecular organization and surface properties using PM-IRRAS, AFM, XPS, ellipsometry, and Raman spectroscopy. Most importantly, UV–vis spectroscopy demonstrated that the photoswitching functionality was retained after film formation and deposition, confirming the successful operation of the tripodal platforms in the surface-mounted state.

These results demonstrate that triptycene-based tripodal platforms provide a robust and versatile molecular architecture for the preparation of functional photoswitchable Langmuir–Blodgett films and surface-mounted molecular devices.

REFERENCES

1. Severa, L.; Santos Hurtado, C.; Rončević, I.; Mašát, M.; Bastien, G.; Štoček, J. R.; Dračínský, M.; Houska, V.; Kaletová, E.; Garza, D. J.; Císařová, I.; Cimatu, K. L. A.; Bastl, Z.; Kaleta, J. Regular Arrays of Rod-Shaped Molecular Photoswitches: Synthesis, Preparation, Characterization, and Selective Photoswitching within Mono- and Bilayer Systems. *Chem. Eur. J.* **2024**, *30*, e2023028.
2. Bastien, G.; Severa, L.; Škuta, M.; Santos Hurtado, C.; Rybáček, J.; Šolínová, V.; Císařová, I.; Kašička, V.; Kaleta, J. Triptycene-Based Tripodal Molecular Platforms. *Chem. Eur. J.* **2024**, *30*, e202401889.
3. Kaletová, E.; Majerová Varga, K.; Santos Hurtado, C.; Bastien, G.; Mašát, M.; Bastl, Z.; Kaleta, J. Triptycene-Based Tripodal Molecular Platforms: A Comparative Study of Photoswitchable Langmuir-Blodgett Films on Metallic and Non-Metallic Surfaces. *Chem. Eur. J.* **2026**, *accepted*.

P02

Chemically Fuelled Active Transport Cascades in Large Unilamellar Vesicles

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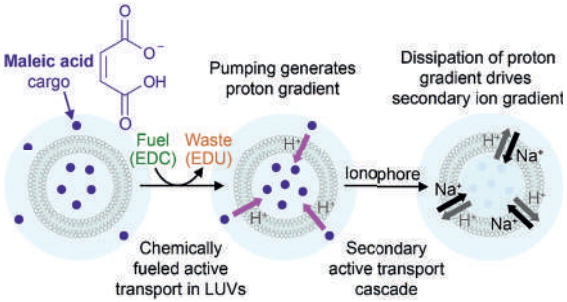
Biological molecular machinery relies on energy transduction to harness chemical energy for active transport, controlling the pumping of ions and molecules between aqueous compartments and across hydrophobic lipid membranes. The mechanisms underpinning these pumps rely on information ratchets, where kinetic asymmetry in a fuel-to-waste reaction results in catalysis-driven active transport.



Developing on recent work of a catalyst-driven information ratchet mechanism pumping small molecule cargo between aqueous compartments through liquid membranes, here we demonstrate the active transport of a small molecule cargo across phospholipid bilayers. Challenges such as analysing and monitoring vesicle suspensions and differentiating the internal and external aqueous environments by conventional analytical methods have been explored. Additionally, the effects of variation in pH and membrane composition have been investigated. Ongoing work focuses on expanding the scope of cargo in phospholipid vesicle systems. The work provides an important step towards the development of life-like compartmentalised nonequilibrium nanotechnologies.[1]

REFERENCES

1. Baxter, W.; Bickerton, L. E.; Liang, K.; Penocchio, E.; Aguilar, J. A.; Ragazzon, G.; Borsley, S. Chemically fueled active transport cascades in large unilamellar vesicles. *J. Am. Chem. Soc.* **2026**. DOI: 10.1021/jacs.6c11418

P03

Theoretical and Experimental Investigation of Energy Storage in Photo-Switchable Molecules for Solar Thermal Storage

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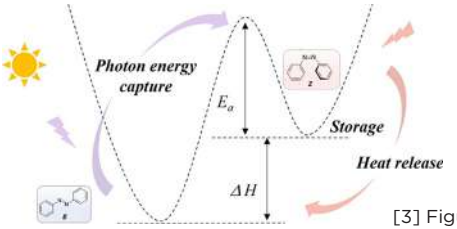
Organic solar panels represent a sustainable and innovative alternative to conventional metal-based devices, addressing the growing demand for energy while reducing associated environmental and economic impacts [1]. One promising approach involves MOST (Molecular Solar Thermal) molecules, which can store solar energy through photoisomerization. Upon irradiation, these molecules are converted from a stable to a metastable state, allowing energy to be stored and subsequently released as heat during the back-conversion process [2,3].



[3] Figure 1

This work investigates how the chemical environment influences the photoisomerization and energy-storage properties of MOST systems. Molecular Dynamics (MD) simulations, Density Functional Theory (DFT) calculations, and experimental characterisation were combined to study the effects of molecular structure, solvent environment, and concentration. Azobenzene, a prototypical MOST molecule, was investigated in different solvents and through structural modifications, including fluorinated derivatives and azobenzene grafted onto peptoids. The norbornadiene/quadricyclane system was also investigated as a complementary MOST platform. Azobenzene (Figure 2) is the prototypical molecule historically used to study this system. In this work, several azobenzene derivatives were investigated, including fluorinated substituents and azobenzene grafted onto peptoïds. Another MOST system investigated in this work is the norbornadiene/quadricyclane system (Figure 3).
The results show that both the chemical environment and concentration can significantly influence the properties of MOST systems, including the photoisomer distribution and the amount of stored energy. The combined computational and experimental approach provides insight into the molecular mechanisms governing these effects and highlights the importance of considering the surrounding chemical environment when designing and optimising MOST materials.

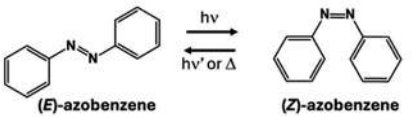


Figure 2

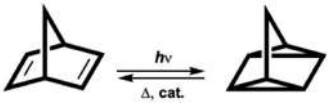


Figure 3

REFERENCES

1. T. s. o. t. Global Commission on the Geopolitics of Energy Transformation et T. Van de Graaf, "A New World: The Geopolitics of the Energy Transformation," 2019.
2. Tassignon, B. et al. (2024) Designing Original Photoswitches Based on Photoresponsive Azobenzene-Containing Peptoids for Molecular Solar Thermal Energy Storage.
3. Dong, Dongfang & Li, Tao. (2024). Multi-azo Photoswitches for Improved Molecular Solar Thermal Energy Storage.

P04

Supramolecular Predisposition Promotes Intramolecular Heavy-Atom Effects for Self-Sensitized Oxidation

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Supramolecular confinement is widely used to control molecular structure,[1] yet its role in directing excited-state pathways, particularly spin-forbidden intersystem crossing (ISC), remains limited. Here, CB[8]-induced folding activates intramolecular heavy-atom effects by juxtaposing a bromine atom and aldehyde group. Structural evidence from solution studies and single-crystal analysis confirms this spatial arrangement. Under white-light irradiation, the resulting complex undergoes efficient self-sensitized photooxidation. Mechanistic studies support triplet–oxygen energy transfer as the operative pathway (**Figure 1**), while preferential substrate binding minimizes product inhibition, establishing supramolecular predisposition as a structural strategy to access spin-forbidden reactivity.[2]

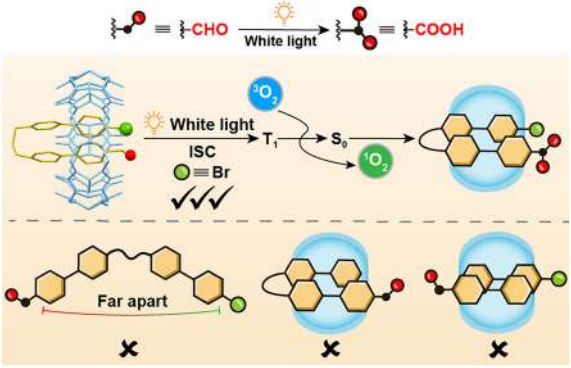

Figure 1. CB[8]-induced folding enforces proximity between the bromine atom and aldehyde, activating intramolecular heavy-atom–driven intersystem crossing and enabling singlet oxygen–mediated photooxidation. In contrast, systems lacking this spatial arrangement do not undergo efficient ISC or oxidation.

REFERENCES

1. Liu, J.; Han, X.; Han, N.; Li, B.; Sun, Y.; Wang, M.; Wu, G. One-Pot 'Click' Synthesis of Ring-in-Rings Complexes with Customizable ϖ-Stacked Dyads. *J. Am. Chem. Soc.* **2025**, *147*, 15838–15846.
2. Li, F.; Sun, Y.; Wu, G. Supramolecular Predisposition Promotes Intramolecular Heavy-Atom Effects for Self-Sensitized Oxidation. *J. Am. Chem. Soc.* **2026**, *148*, 31054–31062.

P05

Light Isn't Magic: Chemically Versus Photochemically Driven Isomerisation of a Double Bond

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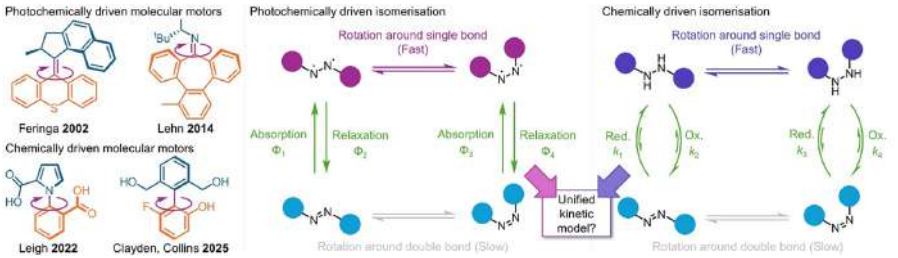
Nonequilibrium processes, for example molecular motors, can be driven by a wide range of energy inputs.[1] Different design considerations must be applied for chemically driven and light-driven systems. The physical rules for such systems differ; photoexcitation and emission are governed by Bose-Einstein relations, while ground-state processes must obey microscopic reversibility.[2,3] Consequently, mathematical descriptors of light-driven systems have often been portrayed as fundamentally different to their chemically driven counterparts.[1,4] However, in many cases the same kinetic models can describe both chemically and photochemically driven systems. Rate constants that describe chemical transformations effectively provide a probability integrated over time that is directly comparable to the probability of a photochemical process as expressed by a quantum yield.



In this work, we seek to experimentally demonstrate the chemical and photochemical isomerisation of a double bond, driving it away from its equilibrium *E*-/*Z*-ratio. This constitutes the first example of a specific nonequilibrium system that can be driven either by light or chemical fuelling, thus allowing direct comparison ot the two processes. We have identified sets of redox reagents that can reduce and oxidise diazo photoswitches between their –N=N– diazene and –NH–NH– hydrazine forms, potentially allowing for chemically driven isomerisation. We have identified azobenzene switches[4] where the equilibrium population is ~50:50, thus maximising the chance of observing a kinetically driven nonequilibrium steady state ratio. Our ongoing work seeks to demonstrate and quantify the kinetic asymmetry for the fuel-driven isomerisation, and subsequently adapt the same kinetic model to the photochemical isomerisation. Ultimately, we hope our work will facilitate the efficient transfer of knowledge between chemical and photochemical systems, thus aiding their future design.

REFERENCES

1. Borsley, S.; Leigh, D. A.; Roberts, B. M. W. Molecular ratchets and kinetic asymmetry: giving chemistry direction. *Angew. Chem. Int. Ed.* **2024**, *63*, e202400495.
2. Astumian, R. D.; Mukherjee, S.; Warshel, A. The physics and physical chemistry of molecular machines. *ChemPhysChem* **2016**, *17*, 1719–1741.
3. Astumian, R. D. Kinetic asymmetry and directionality of nonequilibrium molecular systems. *Angew. Chem. Int. Ed.* **2024**, *63*, e202306569.
4. Bandara, H. M. D.; Burdette, S. C. Photoisomerization in different classes of azobenzene. *Chem. Soc. Rev.* **2012**, *41*, 1809–1825.

P06

Motor-based DNA-binder with photocontrolled affinity

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DNA is a polynucleotide with a double-stranded helical structure, which contains the genetic information of all living organisms and plays a crucial role in life.[1,2] Controlling the structure of nucleic acids allows the study and modulation of in situ genetic processes (DNA repair, replication, and transcription) and associated cellular functions.[1,2,3] For this purpose, numerous external stimuli could be employed, such as light.[1,2,3]
Particularly, molecular photoswitches provide a non-invasive, reversible, spatially and temporally controlled approach to modulate biological activity through structural isomerization.[4] In DNA modulation, photoswitches have been widely employed as covalent nucleoside surrogates.[1] Photoswitchable noncovalent DNA binders are synthetically more attractive, as they do not require oligonucleotide modification and can be applied in vivo. Their efficiency, however, depends on the binding mode, which is difficult to predict.[1]
Nevertheless, the first visible light-driven switchable DNA-intercalators were developed to control DNA and nucleosome binding.[3] Additionally, our group synthesized the first molecular motor-based DNA hairpin to control DNA hybridization under physiological conditions. This approach offers greater precision and photocontrol due to the multistate character, unidirectional rotation, and helicity inversion during rotation.[2] In our study, we describe the synthesis of a molecular motor-based DNA-binder, explore its motor properties, and investigate its noncovalent interactions with DNA.

REFERENCES

1. Lubbe, A. S.; Szymanski, W.; Feringa, B. L. Recent developments in reversible photoregulation of oligonucleotide structure and function. *Chem. Soc. Rev.* **2017**, *46*, 1052–1079.
2. Lubbe, A. S.; Liu, Q.; Smith, S. J.; de Vries, J. W.; Kistemaker, J. C. M.; de Vries, A. H.; Faustino, I.; Meng, Z.; Szymanski, W.; Herrmann, A.; Feringa, B. L. Photoswitching of DNA Hybridization Using a Molecular Motor. *J. Am. Chem. Soc.* **2018**, *140*, 5069–5076.
3. Heinrich, B.; Bouazoune, K.; Wojcik, M.; Bakowsky, U.; Vázquez, O. ortho-Fluoroazobenzene derivatives as DNA intercalators for photocontrol of DNA and nucleosome binding by visible light. *Org. Biomol. Chem.* **2019**, *17*, 1827–1833.
4. Velema, W. A.; Szymanski, W.; Feringa, B. L. Photopharmacology: Beyond Proof of Principle. *J. Am. Chem. Soc.* **2014**, *136*, 2178–2191.

P07

Mechanochemistry of Artificial Molecular Motors

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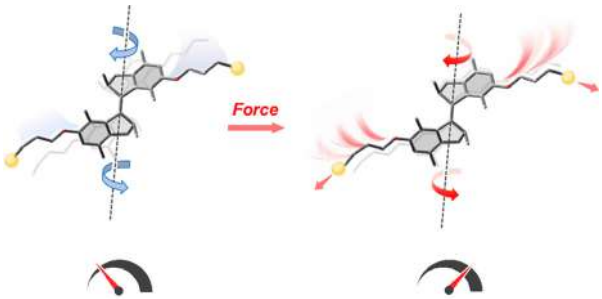
Artificial molecular motors convert light and thermal energy into directional motion and are widely integrated into soft materials to control macroscopic properties. Yet, unlike their biological counterparts, they typically operate independently of mechanical load. In living systems, by contrast, force directly regulates motor kinetics: the rotary motor of Escherichia coli adjusts its rotation speed under external load, and kinesin modulates its walking speed according to the load it carries. Whether artificial molecular machines can similarly couple mechanical force to their operational speed has remained unresolved[1-2].

Here we demonstrate that artificial molecular motors accelerate their rotational frequency in response to mechanical load. By quantifying the force-induced acceleration of helix inversion, which is the rate-limiting step in the rotary cycle, we show that applied force directly enhances this key kinetic transition. These findings establish a strategy for mechanically regulating molecular motor function in soft matter and lay the groundwork for adaptive materials in which artificial molecular machines operate as stress-responsive mechanochemical elements.



REFERENCES

1. O'Neill, R.T.; Boulatov, R., The many flavours of mechanochemistry and its plausible conceptual underpinnings. *Nat. Rev. Chem.* **2021,** *5*, 148–167.
2. Pollard, M.; Klok, M.; Pijper, D.; Feringa, B., Rate Acceleration of Light-Driven Rotary Molecular Motors. *Adv. Funct. Mater.* **2007***, 17*, 718-729.

P08

Light-Gated Control of Brownian Rotation by a Molecular Motor

Lukáš Severa,[a] Kateřina Bezděková,[a,b] Katarina Majerová Varga,[a] Guillaume Bastien,[a] Miroslav Stroka,[a] Ivana Císařová,[c] Martin Dračínský,[a] Jiří Kaleta[a]

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Controlling stochastic molecular motion in a predictable manner remains a major challenge in the development of functional molecular systems.[1,2] Here we demonstrate that a light-driven molecular motor can reversibly regulate Brownian rotation through remote steric interactions (Figure 1).[3] We integrate an overcrowded alkene motor within a rigid triptycene scaffold, where it acts as a reversible steric gate for an alkynyl-linked anthracene rotor. Photoisomerization modulates the steric environment around the rotor axis, switching the system between fast Brownian rotation and a sterically hindered regime. Variable-temperature NMR spectroscopy reveals that one thermodynamically stable motor state exhibits rapid Brownian rotation of the anthracene unit about the alkynyl C–C≡C–C axis, whereas the other stable state displays hindered rotation, giving rise to two distinct rotameric states at low temperature. Density functional theory calculations reproduce this behavior and show that the rotational barrier increases from 20 to 51 kJ mol^{-1} due to increased steric congestion imposed by the motor framework. These results demonstrate that light-driven molecular motors can reversibly regulate stochastic molecular motion through steric control, providing a general strategy for coupling directional and Brownian dynamics within a single molecular system.

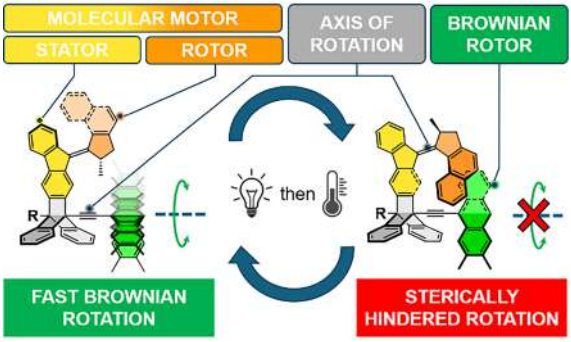

Figure 1: Conceptual design and operating principle of a light-gated molecular system controlling Brownian rotation.

REFERENCES

1. Arpa, E. M.; Durbeej, B. Molecular Photogearing for Controlling Rotary Motion at the Nanoscale. *ChemPlusChem* **2026**, *91*, e202500742.
2. Gerwien, A.; Gnannt, F.; Mayer, P.; Dube, H. Photogearing as a Concept for Translation of Precise Motions at the Nanoscale. *Nat. Chem.* **2022**, *14*, 670-676.
3. Severa, L.; Bezděková, K.; Majerová Varga, K.; Bastien, G.; Stroka, M.; Císařová, I.; Dračínský, M; Kaleta, J. Light-Gated Control of Brownian Rotation by a Molecular Motor. *Angew. Chem. Int. Ed.* **2026**, *under revision*.

P09

Mechanical Regulation of Water-Soluble Molecular Motors in Biological Membranes

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Artificial molecular motors convert light into directional molecular motion and provide a promising platform for constructing dynamic biomimetic systems.[1-3] This work aims to incorporate water-soluble molecular motors into lipid membranes and investigate how membrane mechanics regulate their rotational dynamics. In Feringa-type motors, the rotation frequency is primarily determined by thermal helix inversion (THI), which is sensitive to membrane viscosity, lipid packing, and mechanical order.[1,2]

We will evaluate the membrane incorporation, orientation, and photochemical behavior of different motor structures and correlate their rotational kinetics with membrane properties. Mechanically regulated THI is expected to provide a kinetic readout of membrane mechanical order while enabling molecular motors to function as active components in biological membranes. This study may facilitate the development of dynamic artificial membranes, light-controlled transmembrane transport, and membrane-based synthetic cell systems.[4,5]

REFERENCES

1. Koumura, N.; Zijlstra, R. W. J.; van Delden, R. A.; Harada, N.; Feringa, B. L. Light-Driven Monodirectional Molecular Rotor. Nature 1999, 401, 152–155.
2. Lubbe, A. S.; Böhmer, C.; Tosi, F.; Szymanski, W.; Feringa, B. L. Molecular Motors in Aqueous Environment. J. Org. Chem. 2018, 83, 11008–11018.
3. Van Dijken, D. J.; Chen, J.; Stuart, M. C. A.; Hou, L.; Feringa, B. L. Amphiphilic Molecular Motors for Responsive Aggregation in Water. J. Am. Chem. Soc. 2016, 138, 660–669.
4. Wang, W.-Z.; Huang, L.-B.; Zheng, S.-P.; Moulin, E.; Gavat, O.; Barboiu, M.; Giuseppone, N. Light--Driven Molecular Motors Boost the Selective Transport of Alkali Metal Ions through Phospholipid Bilayers. J. Am. Chem. Soc. 2021, 143, 15653–15660.
5. Guinart, A.; Doellerer, D.; Qutbuddin, Y.; Zivkovic, H.; Branca, C.; Hrebik, D.; Schwille, P.; Feringa, B. L. Photoswitchable Molecular Motor Phospholipid: Synthesis, Characterization, and Integration into Lipid Vesicles. Langmuir 2025, 41, 3961–3970.

P10

Spin-State Photoswitching Drives Dual Rotors

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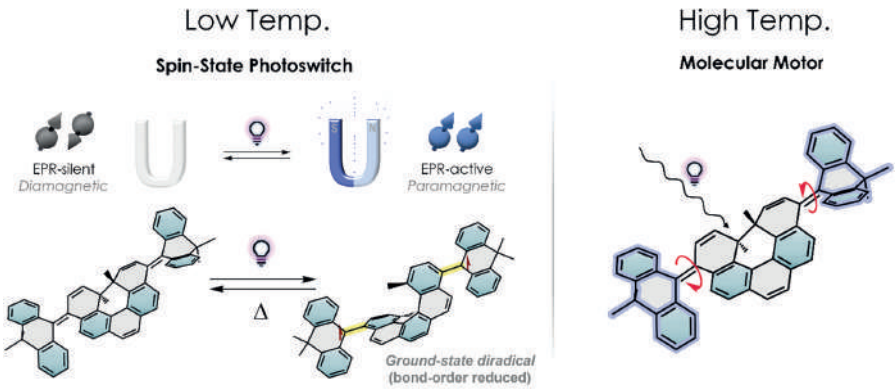
Light-driven molecular motors operate through photochemical *E/Z* isomerization (PEZ) followed by thermal helix inversion (THI).[1] Since the rise of molecular motor science, the fundamental process of PEZ via an excited state species and a torsional motion remained largely unchanged.[2] Here we report a [5]helicene-based molecular machine in which spin-state photoswitching generates a metastable ground-state diradical that replaces the highly transient bond-order reduction of conventional motors.[3] Dependent on the temperature, the system behaves like an organic spin-state photoswitch below 95 K,[4,6] or a molecular motor above 135 K. The long-lived diradical species at low temperature enables direct spectroscopic observation of the PEZ intermediate and establishes an alternative pathway for molecular rotation. Combined with a dual-rotor architecture in which a single excitation event generates two localized radical centers — one at each rotational axle — these findings introduce ground-state bond-order engineering as a new design principle for light-driven molecular motors.



REFERENCES

1. Koumura, N.; Zijlstra, R. W.; van Delden, R. A.; Harada, N.; Feringa, B. L. Light-driven monodirectional molecular rotor. *Nature* **1999**, *401*, 152–155.
2. Costil, R.; Holzheimer, M.; Crespi, S.; Simeth, N. A.; Feringa, B. L. Directing Coupled Motion with Light: A Key Step Toward Machine-Like Function. *Chem. Rev.* **2021**, *121*, 13213–13237.
3. *unpublished result.*
4. Günther, K.; Grabicki, N.; Battistella, B.; Grubert, L.; Dumele, O. An All-Organic Photochemical Magnetic Switch with Bistable Spin States *J. Am. Chem. Soc.* **2022**, *144*, 8707–8716.
5. Schlecht, J.; Lohmiller, T.; Thielert, P.; Douglas, C.; Gather, M.; Richert, S.; Dumele, O. *Angew. Chem. Int. Ed.* **2025**, *64*, e202515144.
6. Miyamura, T.; Schlecht, J.; Dumele, O. *Angew. Chem. Int. Ed.* **2025**, *64*, e202512691.

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