

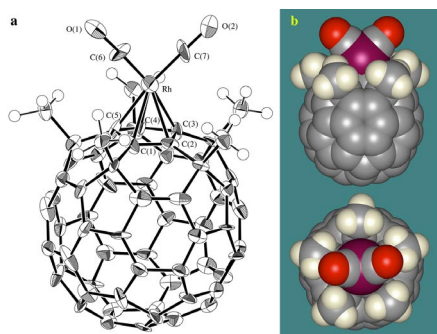
# 物理有機化学研究室

## 研究ハイライト

本研究室は、複雑な電子状態を持つ開殻反応活性種、多様な集合状態を持つ多元素系有機金属活性種、および反応中心を取り囲む反応場全体の動態を制御することで、高度の機能性を持つ有機分子を創出することを目的として研究を進めている。新たな反応、新たな分子の発見創出を目指した実験研究と、大規模量子化学計算による反応機構の解明を併行して進めている。

### (1) フラーレン金属錯体の合成

化学修飾されたフラーレンは、そのユニークな化学的および物理的特性から、新たな機能性分子への応用の可能性に富む興味深い分子である。我々はフラーレンと遷移金属フラグメントからなる複合分子に注目し、新しい種類の触媒や材料を創出することを目的として研究を行っている。今回、メチル基が5つ付加したフラーレンをもつ、ロジウム錯体  $\text{Rh}(\eta^5\text{-C}_{60}\text{Me}_5)(\text{CO})_2$  の合成に成功し、その電気化学的な特性やヒドロシリル化の触媒活性を調べた。その結果、これら遷移金属—フラーレン錯体は、中心金属、シクロペンタジエニル部位、フラーレン底部の  $50\pi$ 電子系の間広がった  $d\pi\text{-}p\pi$ 共役系を有するこれまでに類例の無い分子であることが明らかとなった。

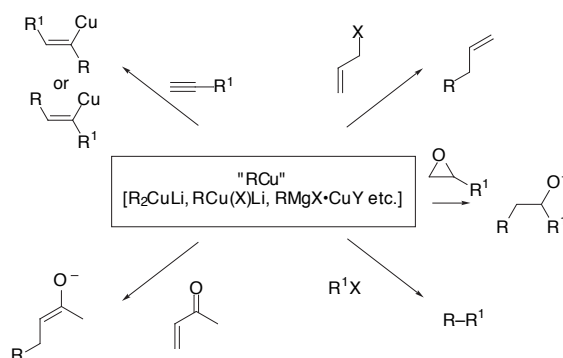


*J. Am. Chem. Soc.*, **122**, 12407-12408 (2000)  
*Org. Lett.*, **2**, 1919-1921 (2000)

### (2) 大規模量子化学計算による有機銅反応の解明

有機銅試薬は、汎用性の最も高い有機金属試薬の一つとして、有機合成化学において広く用いられている。我々は有機銅錯体の反応性を量子化学軌道計算によって解析し、反応発見以来50年経てなお反応機構の不明だった有機銅の基本反応の反応経路を次々と解明している。今回は共役付加反応における配位子および添加剤の働きを明らかにすると同時に、

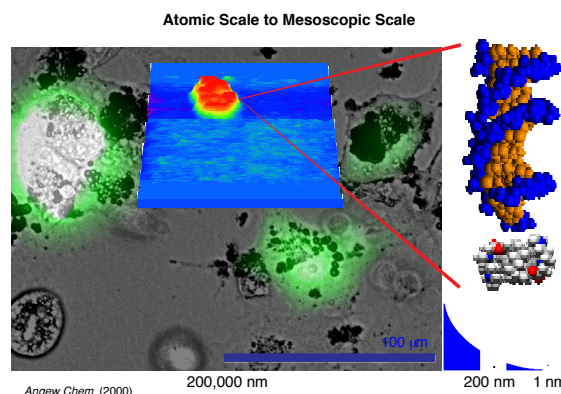
$\text{S}_{\text{N}}2$ 型の求核置換反応の反応機構を明らかにすることが出来た。中間体、および遷移構造の詳細な電子状態の解析から、有機金属クラスターを形成する有機銅(III)中間体からの還元的脱離による炭素—炭素結合生成が、最も重要な過程であることが確認された。「何故、銅であるのか？」という根源的な疑問への解答が漸く得られようとしている。



*J. Am. Chem. Soc.*, **122**, 1826-1827 (2000)  
*J. Am. Chem. Soc.*, **122**, 7294-7307 (2000)  
*Angew. Chem. Int. Ed.*, **39**, 3750-3771 (2000)

### (3) DNA キャリアによる遺伝子の発現制御

第3の炭素同素体として注目されているフラーレン、カーボンナノチューブ類を鍵化合物として、当研究室独自の化学変換反応による機能性分子の創製を行っている。なかでも生体高分子を標的とした機能性分子に着目し、DNA結合型フラーレンの設計・合成を行った。機能探索によりDNA結合型フラーレンは結合したDNAを動物細胞に導入し、その遺伝子を発現させる機能を持つことを見いだした。遺伝子導入試薬の開発は遺伝子治療分野で発展が期待されている基礎技術である。本研究は適切な分子設計を施したフラーレンが薬物運搬システムとして有望であることを示す初めての研究である。



*Angew. Chem.* (2000)

*Angew. Chem. Int. Ed.*, **39**, 4254-4257 (2000)  
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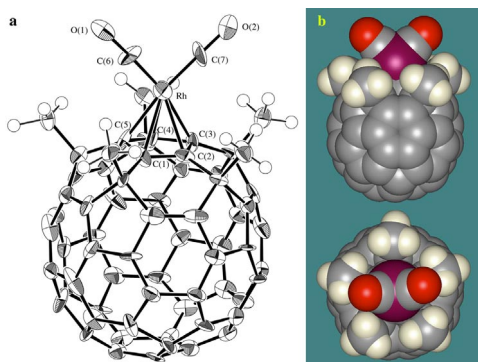
# PHYSICAL ORGANIC CHEMISTRY

## Annual Research Highlights

The objective of this research group is the development of novel reactions that will generate novel strategies for formation and cleavage of chemical bonds connected to a carbon atom. To this end, we are studying the behavior of molecules of complex electronic and structural properties such as open shell reactive intermediates, polyatomic compounds and chemical environments where reactions take place.

### (1) "Synthesis of transition metal-fullerene complex"

Chemically modified fullerenes have attracted much interest owing to their potential applicability as functional molecules having unique chemical and physical properties. We have focused on the hybridization of the fullerene with transition metal fragments to create new catalysts and material. We successfully synthesized the rhodium complexes bearing penta-methylated [60]fullerene,  $\text{Rh}(\eta^5\text{-C}_{60}\text{Me}_5)(\text{CO})_2$ . Electrochemical properties and catalytic activities of hydrosilylation of the new molecule were investigated. These results indicated that transition metal-fullerene complex has an extended  $d\pi$ - $p\pi$  conjugate system among the metal center, the cyclopentadienide on a pole, and the residual  $\text{C}_{50}/50$ - $\pi$  electron system.

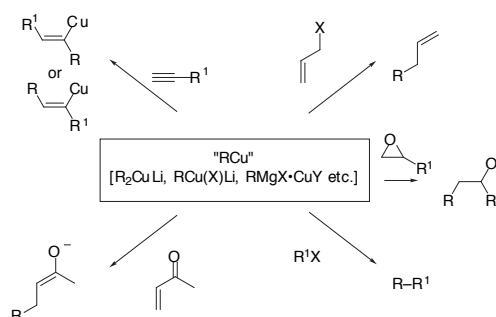


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### (2) "Theoretical studies on organocuprate reaction mechanism"

We have focused on the organocopper reactions, which have been recognized as one of the most important synthetic reactions in organic chemistry. Recent development in computational chemistry now allows us to understand the complicated molecular events in reaction flasks. With the aid of large scale quantum mechanical calculations, we have shown the importance of the cooperative effects of polymetallic

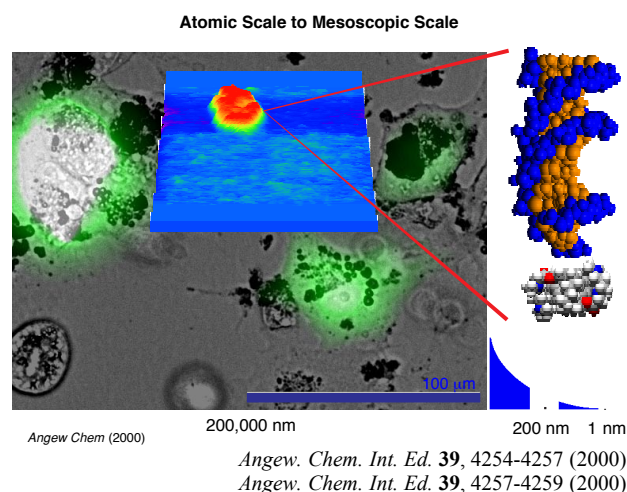
clusters in carbocupration and conjugate addition reactions. The same principle was found to be applicable to the other representative organocopper reaction, such as  $\text{S}_{\text{N}}2$  reaction with haloalkanes and epoxides. Based on the polymetallic cluster mechanism, acceleration effect of the Lewis acidic additives, such as  $\text{BF}_3$ , was explained for the first time. These studies give not only a mechanistic insight but also a guiding principle to design the reactions.



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### (3) "Creation of new organic functional molecules by way of fullerene functionalization"

Based on the development of new synthetic methods of organofullerenes, we have aimed at the design and synthesis of functional molecules. We focused on the development of functional molecules that target important biomolecules and created a new DNA binding fullerene. After searching biological functions, we found that the DNA binding fullerene can deliver excellular DNA into mammalian cells and induce expression of its foreign genes. Gene delivery is one of the important techniques for development of the gene therapy.



*Angew Chem* (2000)

*Angew. Chem. Int. Ed.* **39**, 4254-4257 (2000)  
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## A. Original Papers

- 1) (H. Ohara), (K. Kudo), (T. Itoh), M. Nakamura, and E. Nakamura: "Fe(III)-Catalyzed Radical Cyclization of Cyclopropanone Thiocetal", *Heterocycles* (Mukaiyama Special Issue), **52**, 505 (2000).
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- 3) M. Nakamura, (A. Hirai) and E. Nakamura: "Iron-Catalyzed Olefin Carbometalation", *J. Am. Chem. Soc.* **122**, 978-979 (2000).
- 4) E. Nakamura, M. Yamanaka, and (S. Mori): "Complexation of Lewis Acid on Trialkylcopper(III) Species. On the Origin of BF<sub>3</sub> Effects on Cuprate Conjugate Addition", *J. Am. Chem. Soc.*, **122**, 1826-1827 (2000).
- 5) H. Isobe, (A. Ohbayashi), M. Sawamura, and E. Nakamura: "A Cage with Fullerene End Caps", *J. Am. Chem. Soc.*, **122**, 2669-2670 (2000).
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- 7) (S. Mori), (A. Hirai), M. Nakamura, and E. Nakamura: "Correlation of Reactivities of Organocuprate(I) and Zincate(II) with d-Orbital Energies of Ate Complexes", *Tetrahedron Symposium in Print*, **56**, 2805-2809 (2000).
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- 9) M. Nakamura, M. Toganoh, (X. Q. Wang), (S. Yamago) and E. Nakamura: "Intramolecular [3 + 2] Cycloaddition Reaction of Dipolar Trimethylenemethane", *Chem. Lett.*, 664-665 (2000).
- 10) M. Sawamura, M. Toganoh, (K. Suzuki), (A. Hirai), (H. Iikura), and E. Nakamura: "Stepwise Synthesis of Fullerene Cyclopentadienide R<sub>5</sub>C<sub>60</sub><sup>-</sup> and Indenide R<sub>3</sub>C<sub>60</sub><sup>-</sup>. An Approach to Fully Unsymmetrically Substituted Derivatives", *Org. Lett.*, **2**, 1919-1921 (2000).
- 11) M. Nakamura, T. Inoue, (A. Sato), and E. Nakamura: "Asymmetric Construction of Quaternary Carbon Centers by Regio- and Enantiocontrolled Allylzincation", *Org. Lett.* **2**, 2193 (2000).
- 12) E. Nakamura, H. Isobe, N. Tomita, M. Sawamura, (S. Jinno), and (H. Okayama): "Functionalized Fullerene as a New Artificial Vector for Transfection", *Angew. Chem. Int. Ed.* **39**, 4254-4257 (2000).
- 13) H. Isobe, N. Tomita, (J. W. Lee), (H.-J. Kim), (K. Kim), and E. Nakamura: "Ternary Complexes between DNA, Polyamine and Cucurbituril, A Modular Approach to DNA Binding Molecules", *Angew. Chem. Int. Ed.* **39**, 4257-4259 (2000).
- 14) M. Sawamura, N. Nagahama, M. Toganoh, (U. E. Hackler), H. Isobe, E. Nakamura, (S.-Q. Zhou), and (B. Chu): "Pentaorgano[60]fullerene R<sub>5</sub>C<sub>60</sub><sup>-</sup>. A Water Soluble Hydrocarbon Anion", *Chem. Lett.* 1098-1099 (2000).
- 15) (A. Hirai), M. Nakamura and E. Nakamura: "Mechanism of Addition of Allylmetal to Vinylmetal. Dichotomy between Allylmetalation and Metalla-Claisen Rearrangement", *J. Am. Chem. Soc.* **122**, 11791-11798 (2000).
- 16) H. Isobe, N. Tomita, and E. Nakamura: "One-Step Multiple-Addition of Amine to [60]Fullerene. Synthesis of Tetra(amino)fullerene Epoxide under Photochemical Aerobic Conditions", *Org. Lett.*, **2**, 3663-3666 (2000).
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- 18) M. Nakamura, T. Inoue, and E. Nakamura: "Synthesis of substituted cyclopropanone acetal by carbometalation and its oxidative cleavage with manganese (IV) oxide and lead (IV) oxide", *J. Organomet. Chem.* (J.-F. Normant issue), **624**, 300-306 (2000).
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