Japan Academy Prize to:

Shinji MURAI Executive Director and Vice President, Nara Institute of Science and Technology Professor Emeritus, Osaka University	and	Shun-Ichi MURAHASHI Professor, Okayama University of Science Professor Emeritus, Osaka University

for "Skeletal Formation and Modification of Organic Compounds
via Transition Metal-Based Molecular Catalysts"

Outline of the work:

Transition metal elements have an oxidation-reduction ability, a coordination ability, and many other chemical properties that typical elements don't have. In particular, design of an appropriate transition metal molecular catalyst allows smooth and repeated promotion of the cleavage and formation of a designated chemical bond of an organic compound. Having taken full advantage of these properties of transition metals, Drs. Murai and Murahashi proposed new principles and methods of material transformation that were difficult to achieve by traditional organic chemistry, and developed many molecular conversion methods having high atom efficiencies. More specifically, using molecular catalysts, including ruthenium and other transition metals, the two scientists attained activation of sp^2 or sp^3 carbon-hydrogen bonds, which are poorly reactive. They developed new molecular conversion methods by creation of many types of reactive species, and these works contributed greatly to academic development of this field of study. These newly developed methods have been widely applied to chemical synthesis of biologically active substances and functional substances, which has contributed to development of industrial technology. These research achievements enable resource-saving and environmentally benign material conversion, and set the direction for realization of a sustainable society in the future.

Through a study of new types of catalytic reactions, Dr. Shinji Murai paved the way for a practical method of application of carbon-hydrogen bonds to synthetic organic chemistry, which until then had been considered almost impossible. This achievement allows conversion of many types of easy-to-obtain compounds which had been considered unreactive because of their nonpolar, simple structures into valuable materials with high efficiencies. The keys to this success are use of a new type of ruthenium complex catalyst, and molecular design of reactive substrates that allows intramolecular coordination into the central portions of catalysts.

Dr. Murai developed a method of synthesis of aromatic ring alkylation with high efficiency and high selectivity through reaction of many types of aromatic ketones and olefins using a ruthenium complex as a catalyst. The reaction efficiency is significantly high, and in many cases, the yields of reaction products are quantitative. This method can be applied to many aromatic compounds other than ketones, and was developed to a more general reaction. This catalytic reaction proceeds according to a multi-stage mechanism. From as early as the 1960s, it was thought that when a carbon-hydrogen bond is used, the cleavage of the carbon-hydrogen bond with a metal in the first stage of a catalytic cycle is the most difficult step of the cycle. Thirty years later, through detailed experiments, Dr. Murai showed that this working hypothesis was incorrect, and clarified that the most important characteristic of the catalytic reaction is smooth progress of the final stage of a catalytic cycle. Proposition of this new guiding principle contributed to significant improvements in this field of study. Dr. Murai discovered these and many other types of new conversion reactions, which led to a new tide of molecular conversion methods in synthetic organic chemistry.

Dr. Shun-Ichi Murahashi proposed a new concept regarding environmentally benign biomimetic oxidation catalysts and neutral catalysts that replace acids and bases, and developed many new forms of catalytic reactions based on this concept. Although oxidation reactions are basic to the chemical synthesis of useful materials and many types of oxidation reactions have been developed, they still often require metal oxides and halogenated compounds, and treatment of waste materials from these substances remains an environmental concern. To make environmentally benign oxidation reactions possible, Dr. Murahashi discovered, from his unique standpoint, new types of oxidation reactions that use transition metal complex catalysts or lumiflavin, an organic molecule, as catalysts by the simulation of the metabolic functions of cytochrome P-450 enzyme or a flavin enzyme. He succeeded, for the first time, in generating an active ruthenium-oxo species that acts as the active iron-oxo species of a naturally occurring cytochrome P-450 without using porphyrin, and developed many new types of environmentally benign oxidation reactions that can be applied to many types of substrates. Because of this achievement, he established effective oxidation reactions of β-lactam, which had been a longstanding problem in pharmaceutical synthesis, and contributed to industrial production of an important intermediate that is common to preparation of antibiotics. In order to study the metabolic functions of metal enzymes and organic enzymes in a complementary manner, Dr. Murahashi started studying the oxidation mechanism of a flavin enzyme with its kinetics, and discovered an oxidation reaction by lumiflavin, an organic catalyst. The aerobic oxidation at room temperature with this catalyst is worthy of special mention, because it is a method with a high efficiency comparable to that of enzyme reactions. These new types of catalytic oxidation reactions have opened up a new academic field and are used widely in the synthesis of biologically active compounds and intermediates of chemical industry products.

Furthermore, Dr. Murahashi discovered a specific reaction of amine with a palladium catalyst in the year 1978, and through a detailed study of the reaction mechanism, revealed the fact that the transition metal complex activates the sp^3 carbon-hydrogen bond at the α position of a hetero atom. With this discovery as a turning point, transition metal complexes, such as low valent ruthenium complexes, can be used to form carbon-carbon bonds through activation of sp^3 carbon-hydrogen bonds of many types of hetero atom compounds. These reactions proceed under neutral conditions without using the traditional strong base catalysts. In addition, Dr. Murahashi discovered that this new catalyst also acts as a strong acid, neutral, acid-base ambiphilic catalyst. This kind of ambiphilic catalyst is extremely effective at multi-stage synthesis, as well as automated synthesis. This is a revolutionary study that paved the way for processes that form no salts.

As stated above, having focused on the chemical properties of transition metal elements, Drs. Murai and Murahashi designed new types of catalysts, developed many new types of chemical reactions, and proved the practical effectiveness of these catalysts and reactions. Their study results are a great contribution to the academy and chemical industrial technology, and are highly valued within and outside Japan.

Major publications by Dr. S. Murai

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