Japanese researchers develop cerium-based method to enable multiple chemical reactions in one vessel

A team from Chiba University introduces redox-adaptive auto-tandem catalysis, using cerium to sequentially perform two reactions in a single container

Most high-performance materials and pharmaceuticals require multiple chemical reaction steps during synthesis, each needing different conditions, reagents, and catalysts. In a recent study, researchers from Japan developed a method known as redox-adaptive auto-tandem catalysis, which enables two entirely different reactions to occur sequentially in a single container using a cerium-based catalyst. This approach allows synthesis under mild conditions while reducing energy use and chemical waste.

The study was led by Associate Professor Shinji Harada from the Graduate School of Pharmaceutical Sciences, Chiba University, and was co-authored by Professor Tetsuhiro Nemoto and Nanami Tsuji, also from Chiba University. It was published online in ACS Catalysis on 3 August 2025.

Most of the drugs, plastics, and industrial materials widely used today are produced through chemical reactions. High-performance and sophisticated substances typically have complex structures, and their assembly involves multiple chemical steps carried out one after another. Each step requires specific conditions, reagents, and catalysts, as well as considerable energy and labour.

Tandem reactions provide one solution by allowing multiple reactions to occur in sequence within the same container without isolating intermediate products or changing catalysts. While repeating the same type of reaction is relatively straightforward, the challenge has been finding a single catalyst capable of enabling completely different reactions.

The Chiba University team developed redox-adaptive auto-tandem catalysis to address this challenge. Their method leverages the catalytic properties of cerium, a rare-earth element. The discovery originated when a reaction flask involving cerium was accidentally left exposed to air, producing an unexpected product. This observation prompted the researchers to investigate cerium further.

Cerium can interconvert between two oxidation states, with each state facilitating different chemical transformations. After testing various cerium-based catalysts, the researchers linked two different reactions in sequence. The first is a ring-forming step that produces an intermediate compound with a five-membered ring structure. The second is an oxidation reaction that adds oxygen to the intermediate to produce the final compound. Each reaction is catalysed by a different oxidation state of cerium, and the process of catalysis shifts cerium to the alternate oxidation state.

“Cerium acts like a chameleon, dynamically changing its function to perform completely different types of reactions sequentially in a single vessel,” said Dr Harada.

Using this method, the team synthesised α-hydroxylated cyclopentenones, compounds valuable for pharmaceutical synthesis, in high yields under mild conditions. The autonomous change in the cerium catalyst between two oxidation states enabled the reactions without external intervention.

"Our findings may lead to lower costs and reduced chemical waste, contributing to greener and more sustainable synthetic processes," added Dr Harada.

The technique requires no hazardous reagents and can be performed with standard laboratory equipment without specialised devices.

The team plans to expand the redox-adaptive auto-tandem catalysis method to other chemical reactions relevant to pharmaceuticals and functional materials. They aim to accelerate drug development, enable innovations in material synthesis, and contribute to new manufacturing technologies with reduced environmental impact.

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