

# Engineers use brilliant X-rays to illuminate catalysis, revise theories

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Lead author Dr. David Mueller using brilliant X-rays to characterize working fuel cells at the Advanced Light Source at the Lawrence Berkeley National Laboratory. He is a staff scientist at the Juelich, Germany, research center. Credit: Michael Machala

Many of today's most promising renewable energy technologies – fuel cells, water splitters and artificial photosynthesis – rely upon catalysts to expedite the chemical reactions at the heart of their potential. Catalysts are materials that enhance chemical reactions without being consumed in the process. For over a century, engineers across the world have engaged in a near-continual search for ways to improve catalysts for their devices and processes.

Against this backdrop, a team of researchers at Stanford has used high-brilliance X-rays in a new way to peer into active reactions using metal oxides as the [catalyst](#). Ceramic-like metal oxides, such as iron oxide, a material similar to rust, are desirable as catalysts because they are more abundant and more stable than typical catalysts made of rare metals like platinum, ruthenium and rhodium.

Although they may be more abundant, metal oxides are also less scientifically understood than their metallic counterparts.

The Stanford engineers were able to use enhanced X-ray technology in a novel way to observe the behavior of individual electrons during these important chemical processes. What they learned has upended long-held scientific understanding of how metal oxide catalysts work.

"A freshman chemistry student would tell you, by intuition, that in a material made up of iron and oxygen – as iron oxide is – it is the iron, the metal ion, that is the catalytically active component. We discovered exactly the opposite. Oxygen ions are the ones gaining and losing electrons most actively. Iron is almost completely inactive," explained William Chueh, an assistant professor of materials science and engineering and senior author of the study published in the journal *Nature Communications*.

The results are a 180-degree shift from what went before, assert Chueh

and colleagues – postdoctoral scholar David N. Mueller and graduate student Michael L. Machala, both of whom work in Chueh's lab, and Hendrik Bluhm, a staff scientist at Lawrence Berkeley National Laboratory. The findings could reshape the search for new and better catalysts.

"We've been looking in the wrong place. We thought oxygen was the spectator, but it's the protagonist, and we can now look to develop new catalysts by modifying the [oxygen ions](#) in these systems," Chueh said.

## **Redox redux**

In reality, the catalyst is consumed and then recreated during the reaction, but the net result is the same: zero effect on the catalyst, but profound implications for humanity.

Catalysts play a fundamental role in our lives, though few outside the community of researchers and engineers who study them know much about how they work. Metal oxides, in particular, are leading candidates for use as catalysts at the heart of a basic chemical reaction known as reduction-oxidation, or "redox" for short. Redox reactions are key to renewable energy uses.

One of the best examples is water splitting. Electricity generated from the sun via solar panels is passed through water. The electric current separates ("splits") the water into its two constituent elements: environmentally beneficial oxygen and clean-burning hydrogen. The hydrogen can then be stored and later burned as fuel to generate electricity when the sun is not shining.

## **A fundamental search**

One of the major hurdles on the path to these [renewable energy](#) applications has been the catalyst. The Chueh team's research represents one of the first times science has used high-brilliance X-rays to look so closely at these reactions. The experiments were performed at the Advanced Light Source at the Lawrence Berkeley National Laboratory. Until recently the reactions under such surveillance had to be done in a vacuum, but no longer.

"It simply wasn't possible to study how gas molecules, particularly oxygen, interacted with the catalyst because we couldn't include them in the experiments. Thanks to these new techniques, we can study oxygen in the reactions," Chueh said.

The advance allowed the researchers to observe and follow the electrons as they do their work and to better understand how they behave during the reactions. What they have learned is "extremely critical" to fundamental-level understanding of catalysts and could lead in exciting new directions in catalyst design, Chueh added. Research like this provides a glimpse of a future in which [metal oxides](#) will become more competitive with traditional catalysts.

"We're working at the most basic levels of science to understand what makes a material tick, and what limits its performance and why. This is fundamental work, but it is inspiring, as well," Chueh said, adding: "It will help us design better technologies from the atomic level up, to someday have great commercial impact."

Provided by Stanford University

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