Converting water into hydrogen more efficiently

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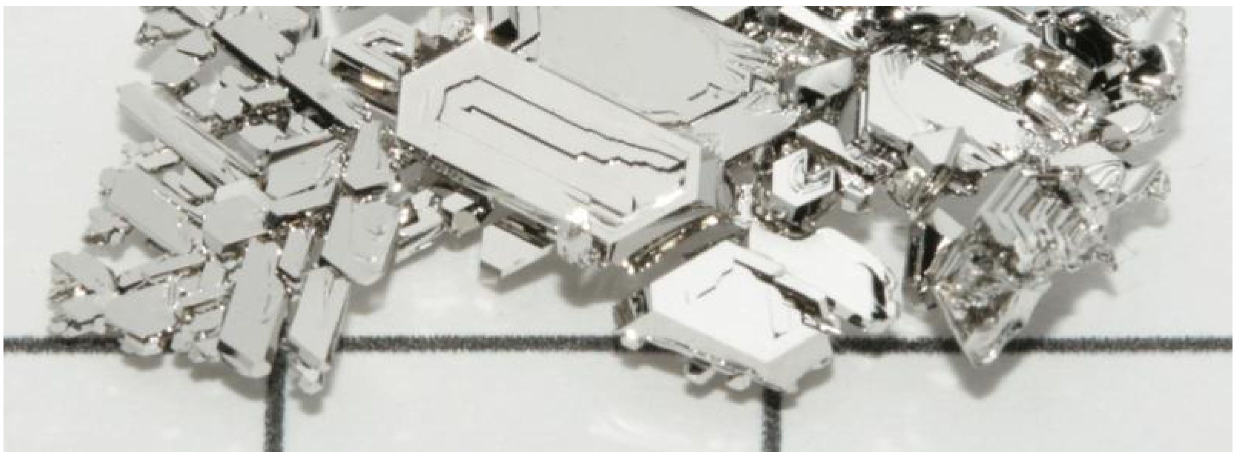

Credit: Leiden University

Scientists have long been puzzled why it is easier to produce hydrogen from water in an acidic environment than in an alkaline environment. Marc Koper comes with an explanation: the reason is the electric field at the surface of the catalyst, which is larger in an alkaline environment, as he writes in a publication in *Nature Energy* on 20 March.

Producing hydrogen more efficiently

Marc Koper is Professor of Catalysis and Surface Chemistry and does research on sustainable energy, such as the use of hydrogen as a fuel.

"Hydrogen is a clean energy source, which we cannot yet make in a clean way on a large scale. Because we know now that the electric field plays an important role, we are better able to fine tune current systems to make them more efficient," says Koper.

To electrochemically convert water into hydrogen and oxygen, electrodes are necessary: a negative cathode and a positive anode. "The cathode is where hydrogen is produced. For this, platinum is the best catalyst, at least in an acidic environment. For the anode, where oxygen is formed, iridium is the best catalyst. And that is the rarest metal on earth."

Cheap nickel

"In an alkaline environment you can use nickel instead of iridium, which is a lot cheaper. However, the production of hydrogen is much harder in an alkaline environment than in an acidic environment. The cathode requires a higher voltage in order to produce hydrogen, which makes the entire process less efficient."

Swimming in an electric field

Marc Koper and his group suspected that the strength of the electric field plays a role in the rate of the reaction. "In an acidic environment, there is a weaker electric field at the platinum electrode at a given voltage than in an alkaline environment. A strong electric field makes the water molecules almost "frozen". Charged particles such as protons and hydroxide ions have little trouble moving when the water molecules move along easily. But in an alkaline environment the electric field is strong, resulting in water molecules that cannot move along when a charged particle needs to pass. For these particles, it is harder to reach the platinum electrode. That is the reason why the reaction is slower than in an acidic environment," Koper illustrates his theory.

We questioned ourselves: how do you measure such as an electric field near the surface of the electrode?" Koper says. "Colleagues at the University of Alicante in Spain developed a special method to measure this field, so our PhD Isis Ledezma-Yanez visited them. The measurements agreed with our model. Next, we will test whether the model is also correct with other catalysts than platinum."

Furthermore, this research offers Koper a new way to improve systems that produce hydrogen out of water. "Prior to this research, we only focused on the binding energy of the catalyst with hydrogen. This should not be too strong, but it should not be too weak either. We now know that the strength of the electric field plays an important role as well. We will carry out further experiments to test this, for instance by varying the composition of the solution.

The way in which hydrogen forms is different in an acidic environment compared with an alkaline environment.

Acidic environment

A proton (a particle with a positive charge) moves through the water solution towards the platinum surface and binds to the platinum as a hydrogen atom.

Two hydrogen atoms that are bound at the surface, bind together and form hydrogen.

Alkaline environment

Water reacts at the platinum surface, resulting in a hydrogen atom bound to the platinum and a negatively charged hydroxide ion (OH^-).

The hydroxide ion moves towards the water solution away from the platinum surface. Due to the strong electric field and the corresponding 'frozen' water, this step is slow.

More information: Isis Ledezma-Yanez et al. Interfacial water reorganization as a pH-dependent descriptor of the hydrogen evolution rate on platinum electrodes, *Nature Energy* (2017). DOI: 10.1038/nenergy.2017.31

Provided by Leiden University

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