Press release
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Understanding the Hidden Electrical Barrier at Solid–Liquid Interfaces

Hydrogen is at the heart of the transition to carbon neutrality, serving as both an energy carrier and a reactant for green chemistry, and even a pathway to convert CO_2 into fuel. However, the large-scale production via electrolysis requires catalysts that are much more economical and efficient than those currently available. Just like many of the world's most critical energy technologies, such as next-generation batteries, hydrogen production depends on a single, invisible boundary: the place where a solid electrode meets a liquid. While this interface is the heart of the energy transition, it has remained notoriously difficult to describe, limiting our ability to design truly efficient and affordable materials. In the study "The role of the Helmholtz potential on electrocatalytic activity" published in *Nature Communications*, Arsène Chemin and colleagues from the Institut Lumière Matière (Lyon 1 Université Claude Bernard / CNRS) and the Helmholtz-Zentrum Berlin have introduced a new theoretical framework connecting charge behaviour in solids and liquids, and demonstrate its implications for the production of hydrogen from water.

It aims to lay the groundwork for a new physical understanding of electrochemistry — one that any lab or industry can build on to accelerate their own breakthroughs in green technology

One Interface, Two Languages

"Until now, we were essentially looking at two different languages," says Arsène Chemin of the Institut Lumière Matière (iLM). "Physicists describe how electrons behave inside the solid, while chemists focus on the molecular reactions in the liquid. But electrochemistry happens precisely where those two meet. Our work shows how these descriptions can be connected into one consistent picture."

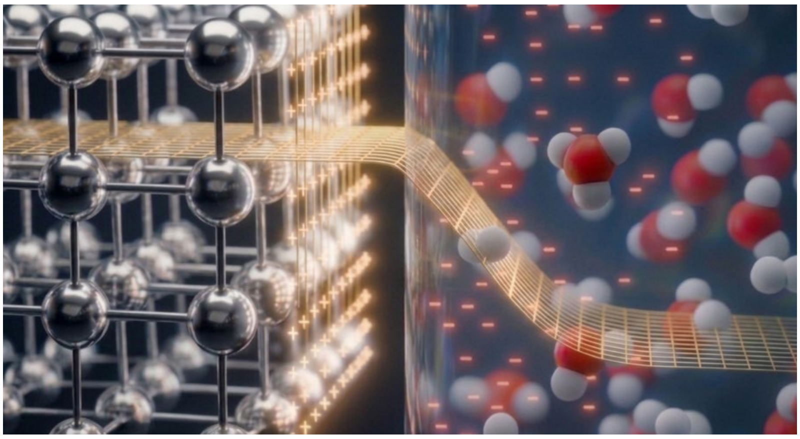
By describing how the electronic energy levels in a material (the Fermi level) equilibrate with the chemical potential in the electrolyte, their model provides a consistent picture of charge separation and its impact on electrochemical reactions.

The Bottleneck Nobody Was Considering

At the interface, electrons do not transfer freely. Instead, the charge redistribution creates variations in the electrical potential over a nanometer scale. The authors identify this as the "Helmholtz potential"— an "electrical hill" at the surface that acts like a speed bump for reactions. While traditional models have overlooked this factor, Chemin's framework reveals it to be one of the primary bottleneck controlling the speed of hydrogen production.

"In fact, the local electric potential appears to be the limiting factor for splitting water into hydrogen at most metal electrodes," explains Chemin.

This perspective helps clarify long-standing observations in electrocatalysis, including why certain surface modifications can significantly enhance performance. It also suggests that classical characterization techniques (such as the Tafel slopes or overpotential) may be incomplete if they don't account for it. Overall, the model provides a unified framework for designing materials based on how they interact with the liquid environment, rather than treating them separately.



Legend: The Helmholtz Potential at the Solid–Liquid Interface. Visualization of the nanometric boundary between a solid electrode (left) and a liquid electrolyte (right). The golden mesh represents what the authors call the Helmholtz potential — the localized 'electrical hill' that governs how fast reactions can proceed at the interface. © Arsène Chemin / ILM (AI generated)

A New Blueprint for Better Electrodes

The framework does not just explain the problem; it points toward potential design strategies, such as the use of semiconductor ultrathin coatings (1-10 nm) on electrodes to reduce the “electrical hill” at the interface, enabling more efficient charge transfer and molecular reactions. Rather than relying solely on trial-and-error approaches, this work provides theoretical guidance for designing electrodes based on more abundant and less expensive materials.

Just the Beginning

Because the model captures how charges equilibrate between solids and liquids at a fundamental level, its implications extend beyond electrocatalysis and hydrogen production. Rather than a final destination, the researchers view this model as a starting point.

"In the past, we were all searching for needles in haystacks," says Chemin. "Now, I hope the research community and industry can use this framework as a map. By better understanding the mechanisms between the solid and the liquid, we can all gain a new perspective on our research and move faster toward the solutions the world needs."

Reference:
Chemin, A., Godeffroy, L., Amans, D. *et al.* The role of the Helmholtz potential on electrocatalytic activity. *Nat Commun* **17**, 4547 (2026). https://doi.org/10.1038/s41467-026-70980-5

About Institut Lumière Matière: The Institut Lumière Matière (ILM) is a joint research unit of the Lyon 1 Université Claude Bernard and the CNRS, based in Lyon, France. The institute brings together physicists and chemists in a multidisciplinary hub built on the synergy between physics, chemistry, and their interfaces.

About Lyon 1 Université: University of Science, Technology, Health and Sport, Lyon 1 Université has more than 49,000 students and has been offering excellent training and cutting-edge research in an attractive environment for more than 50 years. Lyon 1 Université is also an innovative university that has seen the creation of nearly 30 start-ups since 2020. Research at Lyon 1 Université is interdisciplinary and focused on the major societal challenges of our time, helping to advance science in France and internationally.

About the CNRS: A major player in basic research worldwide, the National Centre for Scientific Research (CNRS) is the only French organisation active in all scientific fields. Its unique position as a multi-specialist enables it to bring together all of the scientific disciplines in order to shed light on and understand the challenges of today's world, in connection with public and socio-economic stakeholders. Together, the different sciences contribute to sustainable progress that benefits society as a whole.

About Helmholtz-Zentrum Berlin (HZB): The Helmholtz-Zentrum Berlin für Materialien und Energie is a German research centre dedicated to understanding and developing materials for a sustainable energy future.

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