Quick-stepping hydrogen causes light bulb to flicker

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At one point in my life, I spent several years trying to understand surfaces. It had come as a shock to me to learn that surfaces rule the world. It came as even more of a shock to discover how difficult it was to understand or even measure what is happening at a surface. That makes a light switch made from a single hydrogen molecule sitting on a surface very interesting for what it can tell us about surfaces.

Before we get to the good stuff, we need to take a trip down (my) memory lane. What makes surfaces so important? What makes them so hard to understand?

An inscrutable dictator

To begin with, we're not talking about surfaces like the one your kitchen table provides for your dinner plates. Instead, the surfaces we're talking about are the ones you'd see if you could zoom in on your kitchen table to the point where individual atoms were visible, and some of the molecules from the air in the room would be bouncing off or occasionally stopping to sit on the surface until vibrations knocked them back off.

My one-word explanation for the importance of these types of

surfaces: catalysts. Almost all of modern life relies on catalysts. In very simple terms, catalysts are surfaces that kick reactions into motion. There is more to them than that, but without the strange behavior we see at these surfaces, life would be very boring.

Surfaces don’t make any of this easy to understand, though. The atoms that make up a surface are in an unusual situation. Inside the material, all atoms are surrounded by their mates in a mutually satisfying way. In the interior, material properties can be understood by examining the structures that hold the atoms in a satisfying way and the symmetries the structure possesses. At the surface, the symmetry is broken, and, like Mick Jagger, can’t get no satisfaction. The atoms’ attempts to find satisfaction is what makes the surface both interesting and frustrating.

That lack of satisfaction has consequences for anything near the surface. Because surface atoms don’t know what to do with their electrons, molecules like water or nitrogen will stick temporarily to a surface. The surface may even tear these adsorbed molecules apart. However, for the most part, the bonds between the surface atoms and the adsorbed molecule are often weak; they constantly break and reform.

This makes the surface an active place, as molecules attach, maybe break up, and reform. The molecules move around, they detach and are replaced by fresh copies. All this activity takes place in just a single layer of material, so any measurement of it is often very weak and takes time to gather. As a result, our understanding of them is incomplete. Imagine that you have to review a movie, but you can only choose between viewing a single frame or the average of all the frames in the movie.

Watching hydrogen wave

That is what makes this latest bit of research interesting. It allows us to get an impression of how a molecule moves about on a surface, albeit in a limited fashion.

The researchers started with a gold surface. They then probed the surface with a very sharp tip of gold—so sharp that it ends in a single atom. The tip is placed less than a nanometer from the surface and is moved around until it finds a hydrogen atom.

The tip also glows. The sharp tip shape confines the local electrons, so, as some electrons jump the gap, others begin to slosh up and down in the tip. This sloshing pushes electrons in the surface around and starts them moving, too. If the incoming electrons have enough energy, the sloshing is vigorous enough to generate visible light. That emission process is very sensitive to anything that stands between the gold surface and the tip.

When the tip arrives over the top of a hydrogen molecule, the molecule provides a much smoother path for the current (something called resonant tunneling). As a result, the electrons in the tip and the surface can’t really start pushing each other about. End result: the hydrogen switches off the glow.

The hydrogen molecule also gains energy from the electrons that pass through. It starts to wave back and forth, like a branch in the wind. And, after a moment, it jumps out from under the tip. The tip starts glowing as a result. But the surface doesn’t like the hydrogen molecule’s new location, so, after a while the molecule jumps back under the tip, quenching the glow. Thus, a single hydrogen molecule can switch the tip’s glow on and off.

More than a flashing light?

That’s nice, but there is another important point here. The optical response of the tip is nearly instantaneous when the hydrogen molecule moves. That means we get a precise view of how long the hydrogen molecule stays, and, once it’s gone, how long it takes to return.

This picture of hydrogen diffusion is one of the more important parts of surface chemistry. Knowing how mobile a molecule is and how fast diffusion occurs is to know something about how fast a chemical reaction can occur (molecules can’t react if they won’t move).

Unfortunately, this particular example of gold and hydrogen is not hugely important, and I’m not sure how well the technique will transfer to other surfaces and different molecules. Both gold and hydrogen are quite special beasts that happen to be just right for each other. I will be happier when I see this done on a surface that is not gold (say platinum) and with molecules like water or a simple organic molecule.

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