

13.56 MHz, that's negligibly absorbed by biological tissues. The sensors are visually transparent, so doctors and nurses can tell at a glance if the skin underneath is becoming irritated. They're waterproof and compatible with MRI and x-ray machines, so they can be left on while the babies are bathed or taken for routine imaging.

Clinical need

The wireless sensors have performed well in clinical trials so far, with no adverse effects on any of the patients. But before they can be approved by the Food and Drug Administration for general use in the US, more rounds of testing are needed to prove that they're just as dependable as the current wired sensors.

Until then, test patients must continue to wear wired sensors too.

While they're waiting on FDA approval, the researchers have been working with hospitals in countries where mortality rates are high, even among full-term infants, due in part to a lack of diagnostic equipment. They have active pilot programs in several countries in Africa, and with grant funding from the Save the Children Fund and the Bill & Melinda Gates Foundation, they'll be deploying their sensors to more sites in the developing world later this year.

Although the cost to hospitals in the US and elsewhere has yet to be determined, the researchers estimate that the wireless sensors could be mass-produced for less than \$20 each. That's less than hos-

pitals currently pay for a set of adhesive-backed leads and connectors that are thrown away after a single use.

Older children and adults can also use the sensors—indeed, the first round of tests was on healthy adult volunteers. “We focused on the NICU because that's where the clinical need was the greatest,” says Xu, “but I also see opportunities for the elderly or for burn victims with compromised skin.”

Johanna Miller

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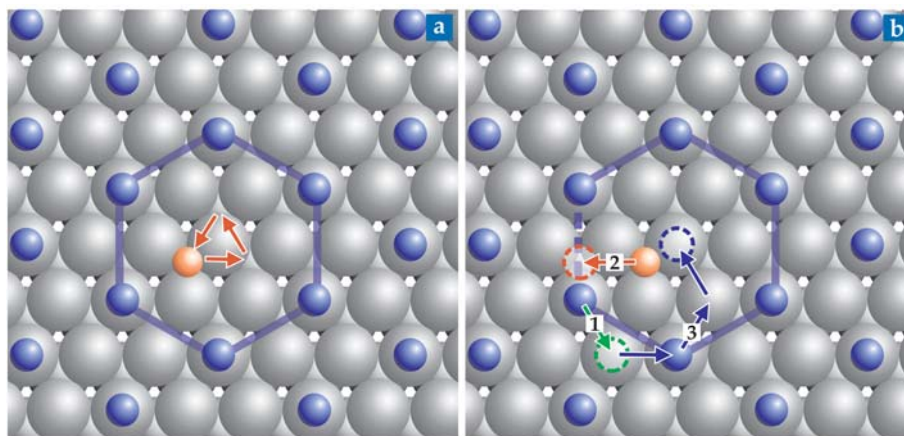
Atoms on a surface quickly slip through crowds

High-speed scanning tunneling microscopy reveals recently identified atomic movements that hasten diffusion.

Most industrial chemicals are the products of catalysis. A catalyst's efficacy depends not only on its ability to facilitate and accelerate reactions but also on its ability to mix with reactants and spread, which, on a surface, is determined by lateral diffusion. Despite the importance of surface diffusion, researchers have yet to observe and understand all its basic atomic-scale dynamics.

Early diffusion studies focused on clean or sparsely populated surfaces with quick diffusion rates. But when the density of atoms increases or there are two or more different species on the surface, as is often the case in industrial processes, diffusion becomes more complicated. Intuitively, one expects higher density and the presence of other particles to slow down diffusion as the adsorbed species get in each other's way. But that doesn't have to be the case.

Joost Winterlin of the Ludwig-Maximilians University Munich and his colleagues have taken a step toward tackling more complicated diffusion dynamics. Using high-speed, variable-temperature scanning tunneling microscopy (STM),



they observed a previously unidentified mechanism that allows for surprisingly rapid diffusion of atoms on a surface crowded with molecules.¹

Diffusion mechanisms

When an atom is alone on a surface, it settles into a low-energy binding site. To move around, it receives a temporary boost to its energy through thermal fluctuations and hops from binding site to binding site. For a higher density of atoms or two species on a surface, diffusion suffers two complications: First, particles must compete for binding sites in an effect called site blocking. Second, particles attract or repel one another. Those factors alter and limit the types of motion available to an atom.

FIGURE 1. TWO TYPES OF ATOMIC MOTION. (a) On a ruthenium surface (gray), an oxygen atom (orange) trapped by a hexagonal ring of carbon monoxide molecules (blue) can move only among the three sites at the center of the hexagonal cage. **(b)** By moving out of position (green arrow), a CO molecule opens the door for the O atom to escape (orange arrow). The CO molecules then rearrange into a new hexagonal pattern, as indicated by blue arrows. (Adapted from ref. 1.)

A few different types of lateral diffusion occur on covered surfaces. One common mechanism in two dimensions, and the most prominent in 3D diffusion, is the vacancy mechanism. As atoms jostle on a surface, vacancies between them change position. A given atom can move only

when a vacancy gets close to it. Because the atom must sit and wait for a vacancy, the process is often slow. A second mechanism, known as direct exchange, was observed for the first time 10 years ago on a chlorine-terminated silicon surface with some Cl replaced with hydrogen.² In direct exchange, two adjacent atoms swap positions. By repeating that process, the Cl atom randomly walks its way across the surface. In a related ring-exchange mechanism, a sulfur atom on a chlorine-covered copper surface exchanges sites with Cl atoms in a ring through a rotation by a site.³

However, it was not clear whether any of those three mechanisms apply to diffusion on a catalyst surface. The allowed motions necessarily change in systems with different types of bonding to the surface and different particle interactions.

Another door opens

In the course of their research on the fundamental steps of catalytic reactions, Winterlin and his colleagues developed and combined two STM operational capabilities—high speed and variable tem-

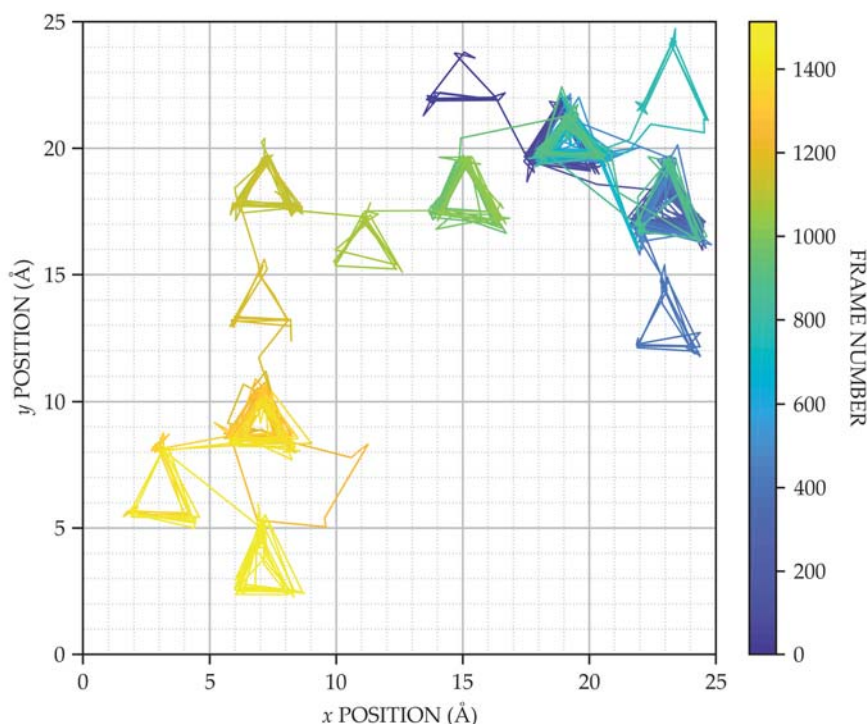


FIGURE 2. TRAJECTORY OF AN OXYGEN ATOM on a highly covered ruthenium surface, as measured by high-speed scanning tunneling microscopy, is plotted as a function of frame number. The triangular patterns arise from the trapping of the O atom by hexagonal cages of carbon monoxide molecules. Despite the high density of CO molecules on the surface, the O atom moves tens of angstroms in two minutes. The measurements were taken at 12 frames per second at 273 K. (Adapted from ref. 1.)

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perature—to observe short-time-scale dynamic processes over a wide range of relevant activation energies. Whereas standard STM takes on the order of a minute to complete one image, high-speed STM completes 50 frames in a second. To achieve the increase in speed, the researchers scan the tip at a constant height rather than the usual method of maintaining a constant current, which requires a delay for the feedback loop.

Variable-temperature STM is difficult to perform because the positioning piezoelectric crystal is sensitive to thermal drift. Winterlin and his colleagues measure between 50 K and 500 K with a beetle-type STM, in which three piezo legs hold the STM tip and scanning piezo. The instrument reduces horizontal thermal drift with its near-cylindrical symmetry and reduces vertical drift because the expansion or contraction of the legs compensates for that of the scanning piezo. Although those capabilities are not unique to Winterlin's group, the marriage of the two is uncommon.

Ann-Kathrin Henss, the first author on the study, recorded 10 STM images per second of an oxygen atom on a ruthenium surface covered with a saturation

layer of carbon monoxide molecules, shown schematically in figure 1. The STM images, taken at various temperatures from 234 K to 303 K, were crisp enough that the team identified the O atom by eye, but there were too many images to analyze them manually. The researchers developed a wavelet-transform-based algorithm, adapted from a biophysics tracking routine for fluorophore-labeled molecules, to identify and track the position of the O atom in each STM image as a function of time. They expected to observe the well-known vacancy mechanism at work with the atom moving only occasionally. Instead, they found that the atom raced around the surface.

Figure 2 shows a representative trajectory for an O atom. The observed movement falls into two categories: circulation among three positions in a triangular pattern and the short-lived migration between the triangular patterns. The researchers found that an O atom (orange in figure 1) prefers to sit in hollow sites at the center of three Ru atoms (gray), whereas CO molecules (blue) occupy

lattice sites directly on top of Ru atoms. When an O atom finds itself trapped inside a hexagonal ring of CO molecules, it jumps among the three available sites at the center of the hexagon, as shown in figure 1a. In the second process, an O atom and a CO molecule appear to exchange positions (figure 1b). The O atom, now free from its initial CO cage, steps into the center of a newly arranged ring of CO molecules. By repeatedly swapping places with CO molecules, the O atom makes its way across the surface.

Making the first move

The experimental time resolution wasn't fast enough to show whether the O and CO move simultaneously, the O moves first, or the CO moves first. Axel Gross of the University of Ulm in Germany and his colleagues joined the project to answer that question through density functional theory calculations. They found that the total activation energy was high for concerted motion and the oxygen-initiated scenario, whereas thermal fluctuations of the CO density easily sufficed to free the O atom.

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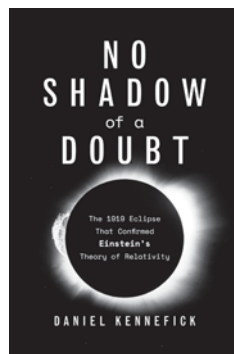
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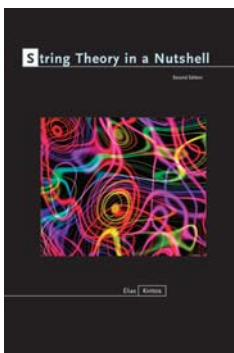
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A CO molecule moves from its post on the hexagonal ring to a site next to an adjacent CO molecule, as shown by the green arrow in figure 1b. The O atom races through the open door (orange arrow) before the CO molecules rearrange to restore the space between them (blue arrows). The final arrangement places the O atom in a new hexagonal ring of molecules. That process flies in the face of the common image of co-adsorbates as stationary obstacles impeding motion. Instead, the CO layer forms a dynamic obstacle course for the O atom to dart through.

Surprisingly, the door-opening diffusion mechanism is almost as fast as the diffusion of O on a bare surface. But atomic processes do not always translate directly into macroscopic diffusion constants. Disorder, defects, and particle-particle interactions influence macroscopic diffusion and perhaps explain why previous diffusion measurements in similar systems showed slower rates.

The situation is further complicated in catalytic reactions, crystal growth, and other chemical processes when reactions and phase transitions must be taken into consideration. It is also not yet clear how common the door-opening diffusion mechanism is. “However, the system investigated—oxygen atoms embedded in a CO layer on ruthenium—should not be special,” explains Winterlin. “It can be generalized to strongly bound particles embedded in a layer of weakly bound other particles, adsorbed on a metal. This situation is quite general in heterogeneous catalysis.”

High spatial- and temporal-resolution *in situ* experiments are important for theoretical studies of diffusion as well. “One can readily provide an *ab initio* description of system thermodynamics,” says Jim Evans of Iowa State University, an expert in modeling nonequilibrium processes at surfaces. “But it is extremely difficult to anticipate the dominant dynamics or kinetics controlling transport processes.”

Heather M. Hill

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The hydrodynamics of a quantum fluid

The behavior of a one-dimensional gas of ultracold atoms confirms a generalized theory.

Hydrodynamics deals primarily with the flow of water and other fluids. A branch of fluid dynamics, it describes the behavior of many-body systems, from molecules in a cup of tea to cars on a highway. The framework, which assumes that each point in a fluid-like collection of particles is locally at equilibrium, characterizes the local quantities that are conserved for an entire system. For a classical fluid like water, those local quantities are mass density, momentum density, and energy density. Models en-

code the evolution of local quantities in the form of continuity equations based on mass, momentum, and energy conservation.

In the quantum world, many-body systems are notoriously difficult to model because the computational memory needed to retain their characteristics grows exponentially with the number of particles. Instead of trying to describe the complex movement of each individual particle, quantum theorists seek ways to explain many-body systems in terms

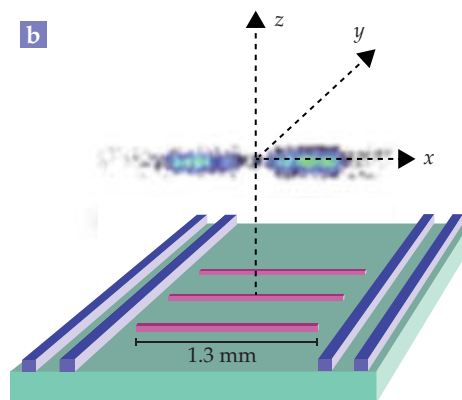
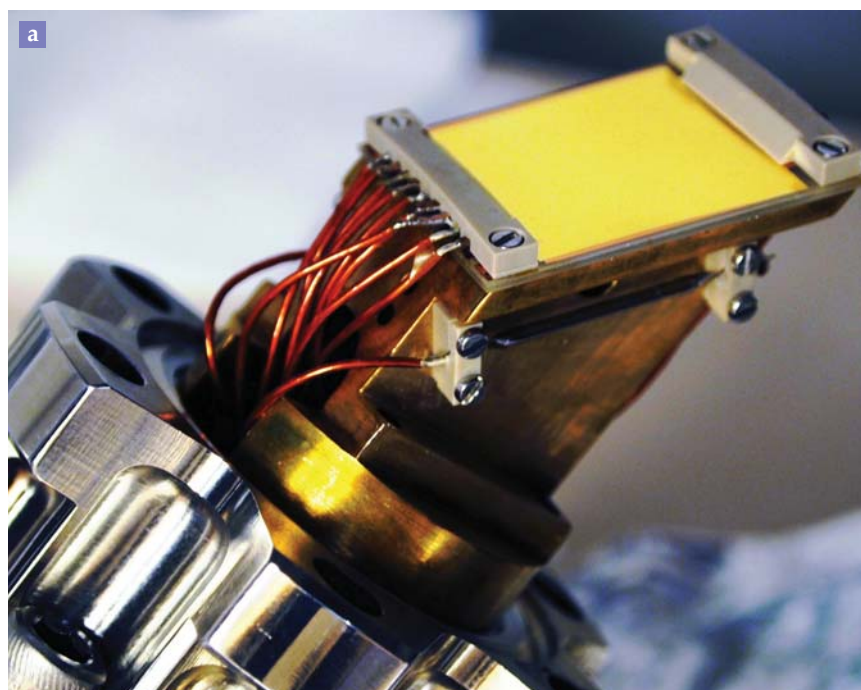


FIGURE 1. A MAGNETIC TRAP ON A CHIP confines a Bose gas of several thousand rubidium atoms. **(a)** Tiny current-carrying wires distributed on the chip create the trap. (Image courtesy of Max Schemmer and Isabelle Bouchoule.) **(b)** The current through the three parallel pink wires creates strong confinement in the *y*- and *z*-directions, trapping atoms 15 μm above the central wire. Current through the four purple wires creates weak confinement; when that current is shut off, the atoms are free to spread along the *x*-axis. (Adapted from ref. 1.)