# Background Information

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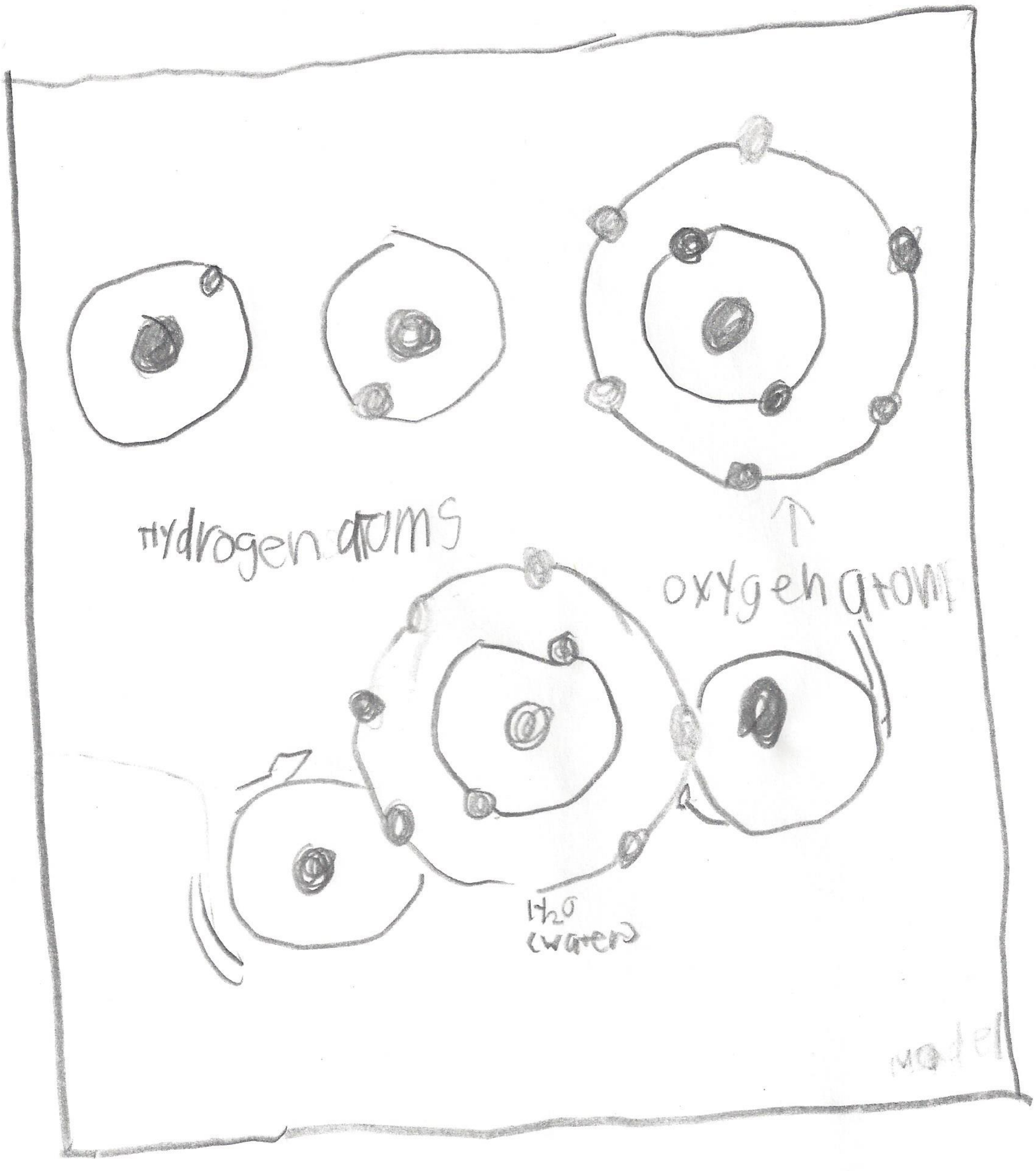
1. The water has no shape of its own. Its shape is the shape of the container.

2. A water molecule is the smallest amount of water you can have. A water molecule is made up of 1 oxygen atom and 2 hydrogen atoms. ($H_2O$)

3. Water can evaporate. When water evaporates, it changes from a liquid into water vapor. Water boils at 100° C. Water can also become a solid when it freezes. Water freezes at 0° C.

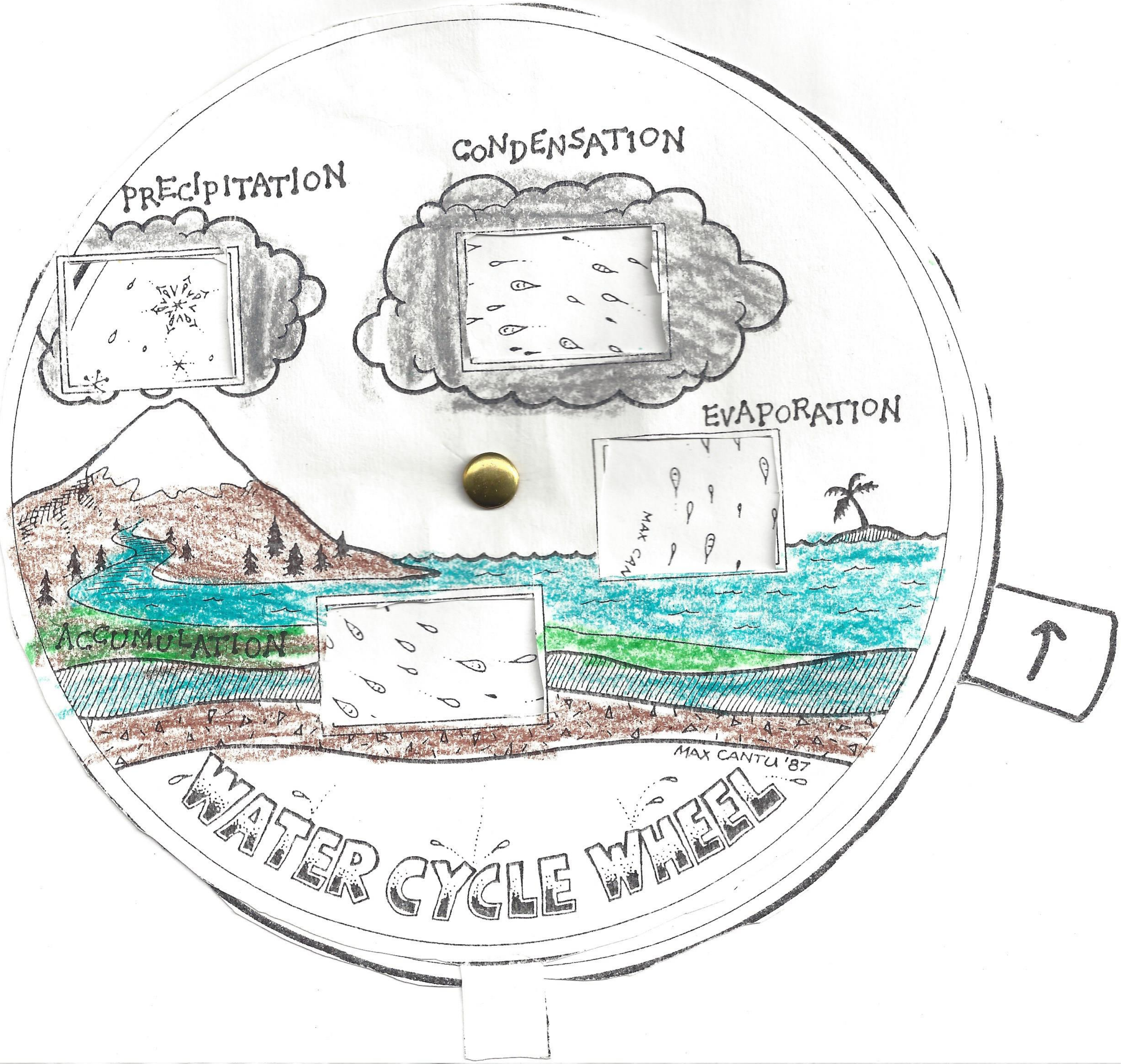
4. A very small amount of heat can get water molecules to move around. The more heat there is, the faster the water molecules will move. Frozen molecules still move, but very slowly.

# water molecules



## The Water Cycle

**Precipitation** - snow, hail, rain, and sleet falls down out of the sky
**Accumulation**- The precipitation gathers together.
**Evaporation** - The molecules of water that accumulated move very, very fast (because they are heated up) and turn into water vapor (a gas).
**Condensation** - The water vapor turns back into liquid. (The water molecules get cooler and move slower.) Clouds form.



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# WATER MOLECULES STAR IN ACTION MOVIES

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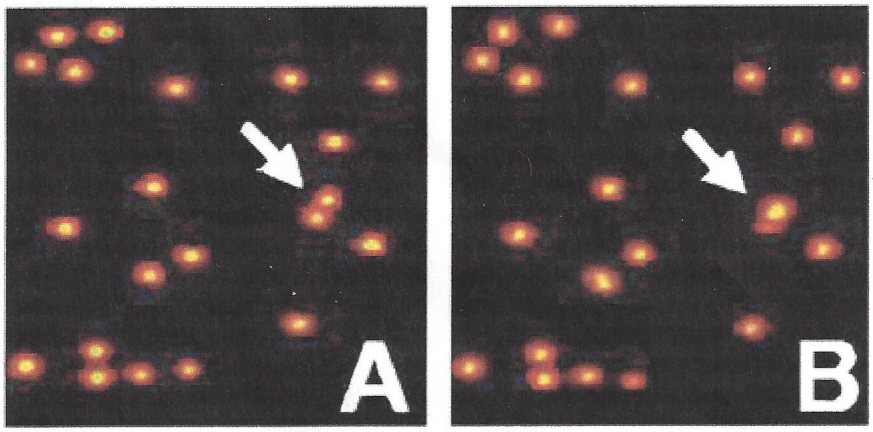
**BERKELEY, CA** — Scientists at the Lawrence Berkeley National Laboratory (Berkeley Lab) have produced the first ever action movies starring individual water molecules on a metal surface. The ending was a surprise even to the producers.

Working with a unique scanning tunneling microscope (STM), a team led by Miquel Salmeron, a physicist with Berkeley Lab's Materials Sciences Division, cooled the surface of a single crystal of palladium, a good catalyst for reactions involving hydrogen and water, to a temperature of about 40 Kelvins (-233 degrees Celsius) in an ultrahigh vacuum. Water molecules were then introduced onto this surface and their motion was tracked with the STM. As expected from previous studies, single molecules migrated across the surface to aggregate into clusters of two (dimers), three (trimers), four (tetramers) five (pentamers) and six (hexamers). The surprise came when the scientists were able to watch the molecules as they moved.

I saw a movie about water molecules moving a round. (They were really REALLY cold and they still moved).



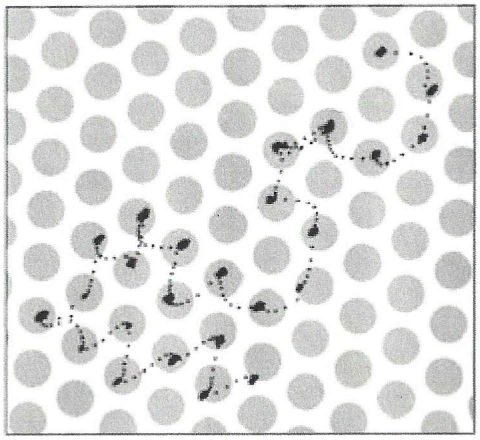

[Click on above image to view streaming RealVideo movie (must have RealPlayer to view)]

These two STM images show molecules of water being adsorbed on a palladium surface at 40 Kelvins. In (A), two individual molecules or monomers approach one another and in (B) they collide to form a dimer.

"Isolated water molecules moved by hopping from one lattice point (on the substrate's crystal) to the nearest neighboring point whereupon if they collided with another water molecule they began to form clusters," says Salmeron. "The speed with which the molecules moved increased by four orders of magnitude when dimers were formed. The mobility of trimers and tetramers was also very high compared to the isolated molecules."

This ran contrary to the usual storyline in which single molecules diffuse or move across a surface more rapidly than clusters. Salmeron likens the situation to pulling either one skater across the ice or a group of skaters connected by a line.

"Since each skater rubs against the surface of the ice, to pull them all together means a lot of rubbing," he says. "The situation can be quite different, however, when the sliding takes place over a corrugated surface, like atoms sliding over the atomic landscape of a surface."



This graphic shows the trajectory of the STM tip as it tracks a water molecule in its random hopping from one nearest neighbor lattice point to another across the crystal of a palladium surface. The image was produced at 52.4 Kelvins.

What he and his colleagues observed in their movies was that the hydrogen bonds which held two, three or four water molecules together in a cluster forced the cluster into a geometric configuration that was mismatched with the lattice of the palladium surface. The individual water molecules within these clusters could no longer be bound to the palladium's lattice points with the same strength as when they were isolated. This allowed dimers, trimers and tetramers to easily slide across the palladium's surface.

When clusters reached five water molecules in size, however, the combined strength of the water-substrate bonds prevailed and the movement of the pentamers slowed or stopped altogether. The addition of a sixth water molecule created highly stable hexamer rings, which spread out as a hexagonal honeycomb structure over the palladium substrate. This, too, brought a surprise.

Explains Salmeron, "The hexagonal honeycomb of water molecules does not exactly match palladium's lattice and as a result honeycombs grow to a certain size and then stop, forming islands across the substrate's surface. As additional water molecules are introduced, they pile up on top of these islands. Slight heating will break these islands up into holes that form beautiful patterns, like nanometer-scale snow flakes."

Working with Salmeron on this study were Toshi Mitsui and Frank Ogletree, both with Berkeley Lab's Materials Sciences Division, and Mark Rose and Evgueni Fomin, students with Physics Department of the University of California at Berkeley. Their results were reported in the September 13 issue of the journal *Science*.

A lot of time, effort, and money goes into water-proofing materials so they don't stain, mildew, rust, or suffer any of the other damages that can happen when something gets wet. The interaction of water with surfaces drives a wide variety of important phenomena that include wetting, corrosion, ice-melting, electrochemistry, dissolution, and solvation. Such interactions are equally important to many biological processes as well. Despite the broad concern, the interactions of individual water molecules with surfaces have remained somewhat of a scientific enigma.

"Numerous fundamental questions regarding the adsorption of water on surfaces and its evolution from isolated molecules to clusters, complete layers, and beyond, remain unanswered," says Salmeron. "Structural probes that analyze cluster formation do not address the important issue of the movement of water on surfaces."

An STM is the ideal instrument for studying the diffusion of individual molecules or atoms along the surface of a material, Salmeron says. Working off a probe that tapers to a single atom at its point, the STM sweeps over a sample area barely a nanometer above the surface. An electrical current is generated by electrons that "tunnel" through the gap between the atoms on the sample surface and the STM tip. This current is extremely sensitive to changes in the gap distance and produces, through a feedback mechanism, displacements in the STM tip that can recorded and translated into topographic images of individual surface atoms. The Berkeley Lab STM is one of the few such instruments in the world that can be operated at the extremely low temperatures needed to slow the process of molecular diffusion down enough for it to be imaged.

"At 40 Kelvins, the diffusion of water on palladium proceeds slowly enough for us to make movies by acquiring sequences of images at 20 second intervals," says Salmeron. "By measuring jump distances and directions in our movie images, diffusion was observed to proceed by random hopping over to the nearest neighbor sites of the palladium substrate."

Diffusion was studied using an atom-tracking technique as well as the movie-making technique. The atom-tracking experiment confirmed the movie-based observations.

"Our findings allow for a deeper understanding of the physics and chemistry of water on surfaces," Salmeron says.

"Nature is always full of surprises and all it takes is to look carefully to discover new things."

Berkeley Lab is a U.S. Department of Energy national laboratory located in Berkeley, California. It conducts unclassified scientific research and is managed by the University of California.

**Additional Information:**

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**Other movie formats:**
AVI [654 KB]
MPEG 2 [271 KB]
QuickTime [149 KB]

Note: depending on how your browser software is configured, you may need to download the movie files to your computer first in order to view them (PC: right-click on link, "Save Target/Link As"; Mac: Ctrl+click on link, "Save this Target as").

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http://www.lbl.gov/Science-Articles/Archive/MSD-action-movies-Salmeron.html