New unidirectional molecular rotor may lead to tiny sensors, pumps, switches

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A University of Colorado at Boulder team has developed the first computer-generated model of a tiny, waterwheel-like molecular rotor that has been harnessed to rotate in one direction at different speeds in response to changes in the strength of an electrical field applied from the outside.

The synthetic molecule features a chemical axle with two attached "paddles" carrying opposite electrical charges, which is mounted parallel to a gold substrate surface, said Professor Josef Michl of CU-Boulder's chemistry and biochemistry department. The researchers found that the microscopic rotor -- constructed with a few hundred atoms -- will turn in a desired direction at a selected frequency using an oscillating electrical field concentrated in a tiny area above the molecule.

Such molecular rotors may someday function as nanotechnology machines and be used as chemical sensors, cell-phone switches, miniature pumps or even laser-blocking goggles, he said. A paper by Michl and former CU-Boulder postdoctoral student Dominik Horinek, the Feodr Lynen Fellow of the German Humboldt Foundation, appeared in the Oct. 4 issue of the Proceedings of the National Academy of Sciences.

In March 2004, the CU-Boulder research group led by Michl reported the synthesis of these molecules and their mounting on a gold surface -- the world's first surface-mounted artificial molecular rotor, which turned spontaneously in random directions at room temperatures. While the team was able to make the rotor "flip" using electricity, the new computer model indicates such rotors can be harnessed to turn in one, desired direction at varying, prescribed speeds, he said.

"We are very pleased," said Michl. "The computer model tells us we will be able to manipulate the frequency of rotor revolutions by changing the strength of the outside electrical field."

The researchers were able to make the new molecular rotor model turn at three different speeds by adjusting the electrical field strength at a given oscillation frequency, he said. The behavior of the rotor responds both to the imposed electrical field and frictional drag within the gold substrate on which the device is anchored, as well as the natural thermal movements of molecules, known as Brownian motion.

The molecular rotors designed and constructed by Michl and his colleagues are an outgrowth of a "Molecular Tinkertoy Kit" the group developed in the 1990s. Made up of chemical rods and connectors tens of thousands of times smaller than the width of a human hair, the parts -- which are made primarily of carbon atoms-- have been used to assemble a variety of simple nanostructures over the past decade.

Complex molecular motors, including the protein, ATPase -- which fuels most cellular processes in living things -- are found throughout the natural world, Michl said. "Ours is much more primitive and one hundred times smaller, and is but a first step."

Michl's group hopes to design a rotor with larger "paddles" and to power it with either a liquid or gas fluid rather than electricity. "Ultimately, we would like to use light pulses to drive the rotor and make it pump fluid. At that point we would have a motor, which is something that actually does useful work, rather than a rotor, which merely idles."

Michl said modeling the behavior of molecular rotors with powerful computers saves a significant amount of time and money in the research process. "Modeling allows us to discard designs that are not fruitful," he said. "We can save a lot of labor and cost by modeling them in the computer first, and only then synthesizing them in the laboratory."

Michl is collaborating with several others in CU-Boulder's chemistry and biochemistry department, including research associates Thomas Magnera and Jaroslav Vacek and graduate students Debra Casher and Mary Mulcahy. He also works closely with Professors Charles Rogers and John Price of the CU-Boulder physics department, as well as faculty members at Northwestern University.

Funded primarily by the U.S. Army Research Office and the National Science Foundation, the research could lead to new technology to produce goggle coatings that would shield human eyes from blinding lasers, said Michl. Arrays of rotors laid down in a protective coating would rest perpendicular to the goggle surface and allow light through. But when a laser pulse arrived at the goggles, the rotors would push the paddles into a parallel position to block incoming light.

Michl is one of 19 CU-Boulder faculty members who have been elected to the National Academy of Sciences, which publishes the Proceedings of the National Academy of Sciences.

Source: University of Colorado at Boulder