MOLECULAR MOTORS

You spin me round

Molecular systems that perform tasks on the nanoscale — molecular machines — need to function on surfaces to enable their application in devices and to ultimately drive forward this area of nanotechnology. Writing in *Nature Nanotechnology*, Saw Wai Hla and colleagues report a new step in this direction, demonstrating the simultaneous rotation of hundreds of molecular rotors adsorbed on a copper surface.

Each molecular rotor is composed of a double-decker molecule. The lower deck — the stator — is designed to anchor the complex on the metal surface, and the upper deck — the rotor arm — is a porphyrin-based molecule with an electron acceptor and an electron donor group located on opposite sides of the porphyrin, resulting in a permanent electric dipole moment. The decks are linked by a rare-earth ion, acting as an atomic ball bearing. The tip of a scanning tunnelling microscope (STM) can be used to apply voltage pulses to the molecules, providing the energy to initiate rotation.

When deposited on Cu(111) at room temperature, the molecules self-assemble to form hexagonal domains. The rotors are stable at the measuring temperature of 80 K, because the thermal energy is not sufficient to overcome the rotational energy barrier in the motor network. In each domain, all the molecular dipole moments point in the same

direction, meaning that the system is ferroelectric. “To our knowledge this is the first realization of a ferroelectric system using molecular motors,” notes Hla.

For applied voltages below 1 V, the rotor arms of the motors can be slightly rotated, but they do not all point in the same direction. Their directions might appear random at first glance, but they are effectively coordinated to minimize the energy; each rotor arm feels the rotation of the neighbouring rotors owing to their mutual dipolar interaction. “Above a threshold voltage of 1 V, up to 500 molecular rotors can be rotated simultaneously,” Hla explains. “Like soldiers in a parade, the rotor arms of the motors rotate and point in the same direction.”

The researchers found that defects in the molecular network are essential for this simultaneous rotation to occur. To start the rotation, it is necessary to apply a net torque on the rotors. In a perfect network, the torque experienced by any rotor as a result of the electric field produced by the STM tip would be balanced by its anticlockwise counterpart felt at the opposite symmetric site, and the result would be a zero net torque on the system. By contrast, if there is a defect — typically a missing

molecule — a net torque appears at the opposite location. Because the electric torque attenuates slowly with distance, rotors relatively far away in the network gain a net torque, enabling the collective rotation.

“We are continuing to develop our understanding of the charge and energy transfer processes in molecular motor networks, and how they work,” says Hla. “For example, standard mechanical engineering cannot be applied to these molecular motors, because they are in a quantum regime, which complicates how energy is transferred between them.” The final goal is to develop synthetic molecular machines that can operate on surfaces and in a solid-state environment.

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