Nanotechnology

Nanomotors Have Places To Go

by Nancy McGuire

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In among the videos of affectionate kittens and Valentine's Day declarations, another clip recently made the rounds of social media. "You're looking at happiness," the caption said, describing the determined march of a myosin molecule dragging a big, blobby endorphin toward the brain's parietal cortex.

Several astute commenters pointed out that this was actually the motor protein kinesin performing the more mundane task of transporting a vesicle along a microtubule inside a cell. Still, it's evidence that nature is several millennia ahead of humans, who began publishing articles on artificial nanomotors in 2004.

Motor proteins hydrolyze adenosine triphosphate to gain energy, which they convert to mechanical work. Biomotors operate well in vivo, but they are difficult to control and modify outside of their original applications. Joseph Wang at the University of California, San Diego (UCSD) reports that kinesin motors functionalized with DNA or antibodies can transport liposomes or nucleic acids along microtubule tracks in lab-on-a-chip devices. These protein motors, however, have limited operational stability in artificial environments; and they require tracks to guide them. (*Biosens. Bioelectron.* DOI: 10.1016/j.bios.2015.04.095)

Nanowires, Janus spheres, and tiny tubes

Artificial nanomotors fare somewhat better. Recently, Andrzej Chałupniak, Eden Morales-Narváez, and Arben Merkoçi* at the Catalan Institute of Nanoscience and Nanotechnology (Barcelona) reviewed three types of artificial nanomotors—wires (or rods), spheres, and tubes—and the systems that propel them in a biomedical context. These basic motor systems also show up in other applications. (*Adv. Drug Deliv. Rev.* DOI: 10.1016/j.addr.2015.09.004)

- **Rods** Lei Shao, Mikael Käll, and colleagues at Chalmers University of Technology (Göteborg) and Örebro University (both in Sweden) made gold nanorod rotary motors that are powered by resonant light scattering. They used these rotors to probe solution viscosity changes and molecular attachment effects. They predict that tiny rotary impellers could drive fluids along nanofluidic channels. (*ACS Nano* DOI: 10.1021/acsnano.5b06311)
- **Spheres** Janus sphere nanomotors have two hemispherical faces: one for propulsion and one with functional groups for the targeted application (e.g., biosensing). Common configurations incorporate metallic thin films on silica or polystyrene microbeads. Anna Balazs at the University of Pittsburgh, Wang at UCSD, and coauthors made Au/Pt Janus spheres, fueled by 5% aq H_2O_2, that sought out and repaired micron-scale cracks in a gold film electronic circuit—a process that simulates wound healing. (See Figure 1 for a schematic of this process.) Octadecanethiol functional groups on the gold side of the spheres attracted them to the hydrophobic substrate beneath the cracks. The spheres formed clusters that spanned the cracks, restoring electrical conductivity across the circuit. (*Nano Lett.* DOI: 10.1021/acs.nanolett.5b03140)

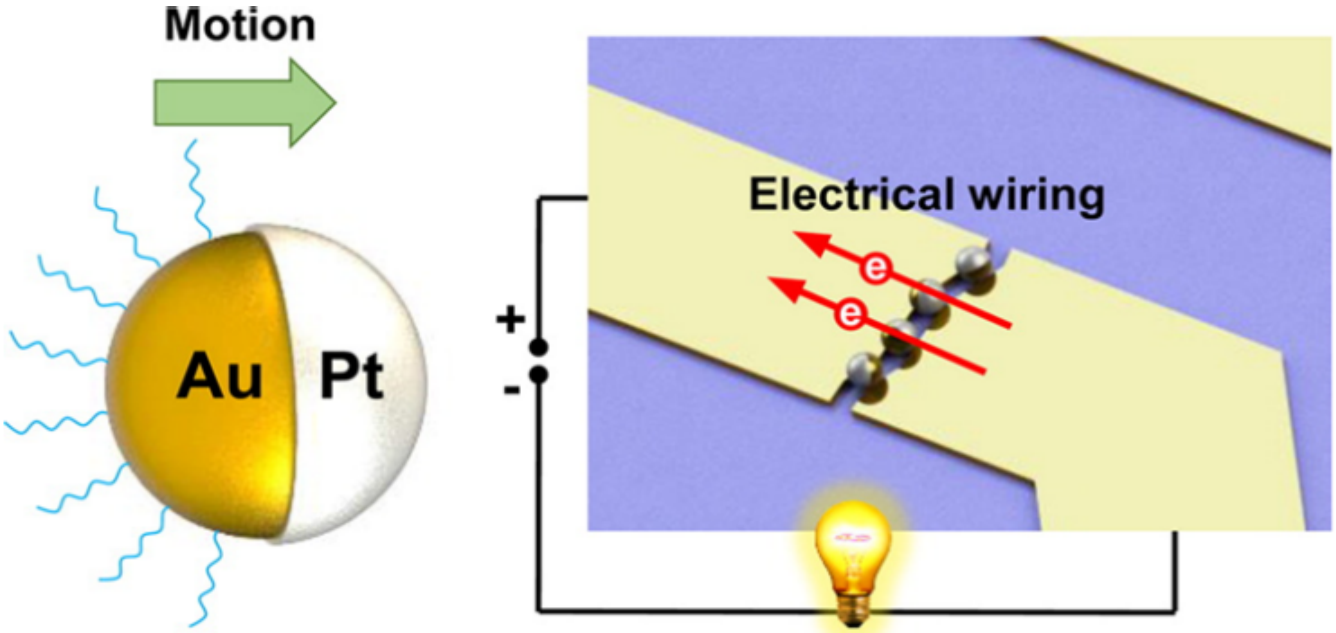

Figure 1

- **Tubes** Sarvesh Kumar Srivastava*, Maria Guix, and Oliver G. Schmidt at the Institute for Integrative Nanosciences (Dresden, Germany) grew catalytically active palladium particles onto thin Ti/Fe/Cr films, which they then rolled into tubes. Immersing the tubes in water containing 4-nitrophenol and $NaBH_4$ (manufacturing waste products that served as fuel) released streams of hydrogen bubbles, which propelled the tubes through the water, scooping up pollutants as they jetted around (Figure 2). (*Nano Lett.* DOI: 10.1021/acs.nanolett.5b05032)

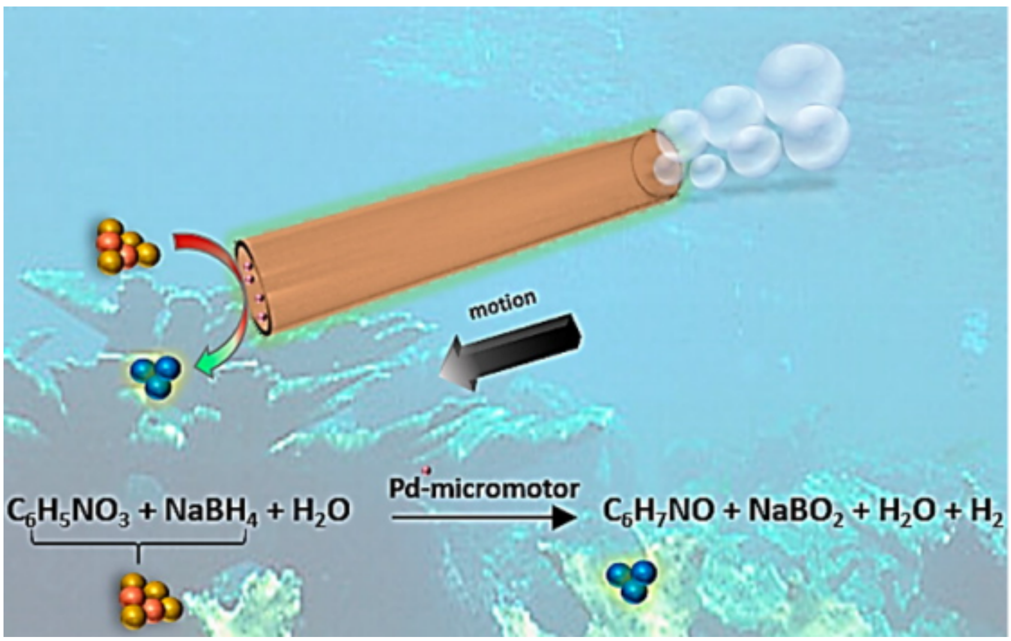

Figure 2

Propulsion

Electromagnetic and acoustic waves have been used to propel nanomotors, but chemical and magnetic propulsion are more common.

Chemical propulsion requires access to fuel; and particle trajectories can be chaotic and hard to control. Chemical propulsion can be coupled with other means of propulsion (e.g., magnetic) that provide directionality. Alternatively, the nanomotors can be guided along microfluidic channels or fiber pathways.

Self-electrophoresis propulsion is typical for nanowires and spheres that have an asymmetric distribution of ions. Changes in the surrounding electric field propel the particles through a liquid medium.

Particles driven solely by an external magnetic field require no fuel, and they are easy to guide. They must contain a ferromagnetic metal, however; and biocompatible or environmentally benign devices may require coupling magnetic and chemical drives.

Last year, Wang and colleagues published the first report of artificial micromotors operating in living organisms. Their zinc-based tubes run on stomach acid and potentially can be used to deliver drug molecules. (*ACS Nano* DOI: 10.1021/nn507097k)

Fernando Martinez-Pedrero and Pietro Tierno* at the University of Barcelona created paramagnetic colloidal “carpets” made from clusters of micropropellers. These clusters, driven across the suspension film by magnetic fields, picked up, transported, and released silica microspheres and yeast cells. The authors manipulated the magnetic fields to steer the carpets around corners and obstacles. The carpets immediately dispersed when the fields were removed. (*Phys. Rev. Appl.* DOI: 10.1103/PhysRevApplied.3.051003)

On a mission

Nanomotors are molecules on a mission, whether it’s fixing cracks, scooping up industrial waste, or running delivery services. Nature may have a head start on the applications, but this relatively new materials science field is rapidly gaining ground and branching out into new territory.

News —Menu

- Press Pacs
- News Releases
- Reactions
- Science Podcasts
- ACS in the News
- Cutting-Edge Chemistry