Tiny DNA 'legs' walk with record fuel efficiency

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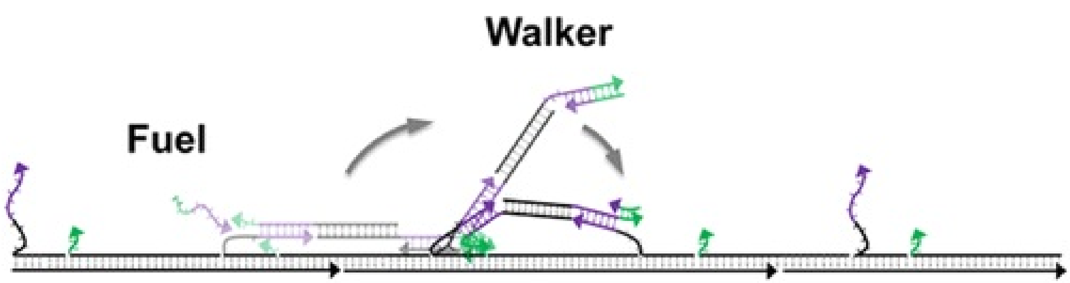

The DNA nanomotor walks using a mechanism called product control, which controls the order in which the products in a chemical reaction are released. This ensures that the nanomotor's back leg always leaves the ground before its front leg. Credit: Liu et al. ©2016 American Chemical Society

(Phys.org)—For the first time, researchers have demonstrated a DNA nanomotor that can "walk" along a track with sustainable motion. The nanomotor also has the highest fuel efficiency for any type of walking nanomotor, or "nanowalker," reported to date, using approximately one fuel molecule per step.

Researchers Meihan Liu *et al.* at the National University of Singapore have published a paper on the DNA nanowalker in a recent issue of *ACS Nano*.

The tiny motor illustrates how purely physical effects can enable the efficient harvest of chemical energy at the single-molecule level. By operating on chemical energy, the new motor functions completely differently than any macroscopic motor, and brings researchers a step closer to replicating the highly efficient biomotors that transport cargo in living cells.

An important characteristic of the new nanowalker is that, like biomotors in living cells, it is an enzyme. This means that it helps initiate the fuel-producing chemical reaction that generates its motion without permanently changing itself or its track. This trait enables repeated, sustainable motion, which has not been achieved by any chemically powered synthetic nanowalker before now. Most other nanowalkers have been "burn-bridge motors," meaning they are not enzymes but instead consume their tracks as their fuel.

Creating enzymatic nanowalkers is very challenging, and so progress in this area has been relatively slow over the past few years. The only other demonstration of an enzymatic walker was in 2009, when researchers designed a nanowalker that, despite being enzymatic, cannot achieve sustainable motion because its track coils over time and eventually halts the motor. This nanowalker uses more than two fuel molecules per step, and studies since then have suggested that two fuel molecules per step is a general threshold for enzymatic nanomotors.

With its capability of sustainable motion and a fuel efficiency of approximately one molecule per step, the new nanowalker represents a leap of progress in this area.

The key to this achievement was finding a physical mechanism for efficiently harvesting chemical energy at the single-molecule level. This mechanism consists of three "chemomechanical gates" that basically ensure that the nanowalker walks by always picking up its back leg and not its front leg.

To do this, these gates physically control the order in which the products are released in the chemical reaction that propels the nanowalker forward. As a result, the DNA nanowalker's back leg dissociates from the track first and takes a step forward before the front leg dissociates. Then when the front leg becomes the back leg, that leg takes a step forward, and the walking cycle repeats. The dissociation of each leg occurs when an enzyme "cuts" one fuel molecule that is bound to the leg, so that one molecule is all that is needed to take one step. Using a fluorescence microscope, the researchers observed that the 20-nm-long nanowalker could move at speeds of up to 3 nm per minute.

As the researchers explain, the product control mechanism is unique to chemically powered nanomotors. It's not used by other kinds of nanomotors, such as those driven by light or electric/magnetic fields, nor by macroscopic motors, which typically burn a large quantity of fuel molecules to generate heat, and then use the heat to generate motion to produce work.

Product control is, however, used in the bipedal biomotors inside living cells, which consume ATP (adenosine triphosphate) as fuel. When the smaller phosphate molecule in ATP is released before the larger ADP (adenosine diphosphate) molecule, the biomotor moves in one direction; when the products are released in the opposite order, the biomotor moves in the opposite direction.

Since the new nanowalker is a rare demonstration of product control in a synthetic motor, the researchers hope that it will guide future development on chemically powered nanomotors toward the ultimate goal of replicating the highly efficient transport exhibited in living cells. One possible next step in this area is to fabricate a train of nanowalkers to demonstrate collective transport, which is a common characteristic of biomotors. These nanomotors could ultimately lead to several novel applications.

"Enzymatic nanowalkers are a key element for replicating the autonomous, repeatable and efficient intracellular transport," coauthor Zhisong Wang, a physicist at the National University of Singapore, told *Phys.org*. "This capability is important as it leads to a variety of nanotechnological applications, such as motor-mounted drug delivery wherever the track leads, down to nanoscale resolution for localization; sensing and signal transduction (by capturing and concentrating chemical agents); automated multi-step synthesis and nanoscale assembly lines; and energy conversation for energy technology."

More information: Meihan Liu *et al*. "Biomimetic Autonomous Enzymatic Nanowalker of High Fuel Efficiency." *ACS Nano*. DOI: 10.1021/acsnano.6b01035