Polymer passage takes time: New theory aids researchers studying DNA, protein transport

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(PhysOrg.com) -- Polymer strands wriggle their way through nanometer-sized pores in a membrane to get from here to there and do their jobs. New theoretical research by Rice University scientists quantifies precisely how long the journey takes.

That's a good thing to know for scientists studying the transport of RNA, DNA and proteins -- all of which count as polymers -- or those who are developing membranes for use in biosensors or as drug-delivery devices.

Researchers led by Anatoly Kolomeisky, an associate professor of chemistry and of chemical and biomolecular engineering, have come up with a theoretical method to calculate the time it takes for long-chain polymers to translocate through nano-sized channels in membranes, like the one that separates the nucleus of a cell from surrounding cytoplasm. RNA molecules have to make this intracellular trip, as do proteins that pass through a cell's exterior membrane to perform tasks in the body.

Primary author Kolomeisky reported the findings this month in the Journal of Chemical Physics. Study co-authors include Aruna Mohan, a former postdoctoral research associate at Rice and now a researcher at Exxon-Mobil, and Matteo Pasquali, professor in chemical and biomolecular engineering and chemistry.

The team studied the translocation of a long polymer molecule, which roughly resembles beads on a string, through two types of nanopore geometries: a cylinder and a two-cylinder composite that resembled a large tube connected to a small tube. Not surprisingly, they found a polymer passed more quickly when entering the composite through the wide end.

"We assume the polymer is relatively large in comparison with the size of the pore, which is realistic," Kolomeisky said of the process, which is akin to threading a rope through a peephole. "A typical strand of DNA could be a thousand nanometers long, and the pore could have a length of a few nanometers."

It's been known for some time that polymers don't just fly through a pore, even when they find the opening. They start. They stop. They start again. And once the leading end has entered a pore, it can back out. Polymers often jitter backward and forward as they progress through a pore, constantly reconfiguring themselves.

"Previous theorists thought that as soon as the leading end reached the channel, the whole polymer would go through," he said. "We're saying it goes back and forth many times before it finally passes."

The key to an accurate description of polymer translocation with single-molecule precision is measuring electric currents that go through the pore. "When the current is high, there's no polymer in the channel. When the current is down, it's in the pore and blocking the flux," he said.

Experiments indicate typical DNA and RNA molecules could pass through a membrane in a few milliseconds, depending on the strength of the electric field driving them. But even that, he said, is much longer than researchers previously thought.

Kolomeisky said the new method works for pores of any geometry, whether they're straight, conical or made of joined cylinders of different sizes, like the hemolysin biological channel they simulated in their research.

The calculations apply equally to natural or artificial pores, which he said would be important to scientists making membranes for drug delivery, biosensors or water purification processes, or researching new methods for sequencing DNA.

More information: Read the abstract at jcp.aip.org/jcpsa6/v133/i2/p024902_s1

Provided by Rice University