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NEWS RELEASE

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Note to Journalists: Osman Basaran will be traveling from Nov. 13-25. His cell phone number is (765) 414-3369. He also can be reached by contacting Emil Venere at (765) 494-4709 (Office), (765) 743-0092 (Home) or venere@purdue.edu. An electronic version or hard copy of the paper also is available from Venere. A publication-quality image is available at http://ftp.purdue.edu/pub/uns/basaran.nanothreads.jpeg

Discovery could lead to new ways to create nano-fibers and wires

WEST LAFAYETTE, Ind. — A research team led by engineers at Purdue University and physicists at the University of Chicago has made a discovery about the formation of drops that could lead to new methods for making threads, wires and particles only a few nanometers wide.

Such nano-threads, wires and particles could, in turn, have numerous applications, including new kinds of composite materials, electronic circuits and pharmaceutical products, said Osman Basaran, a professor in Purdue's School of Chemical Engineering.

The researchers made the discovery while studying how liquid drops and gas bubbles are formed by nozzles, such as those in inkjet printers. A widely accepted universal rule holds that, no matter what the liquid or gas is made of, drops and bubbles always break away from a nozzle the same way: As the drop is forming, it is attached to the nozzle by a thin segment of liquid or gas. This connecting segment grows progressively thinner, and as its width gets closer and closer to zero it breaks at a single point and the drop falls away from the nozzle.

"This breaking region, which I and others have been studying, has some really amazing properties," Basaran said. "It always breaks the same way, no matter how big a nozzle is or how fast you are flowing the liquid."

The researchers, however, have discovered an exception to this no-longer universal rule, Basaran said.

Findings will be detailed in a paper to appear in Friday's (11/14) issue of the journal Science. The paper was written by former Purdue chemical engineering doctoral student Pankaj Doshi, who is now a postdoctoral fellow at the Massachusetts Institute of Technology; Itai Cohen, a former physics doctoral student at the University of Chicago and now a postdoctoral fellow at Harvard University; Wendy W. Zhang, an assistant professor of physics at the University of Chicago; Michael Siegel, a mathematician from the New Jersey Institute of Technology; Peter Howell, a mathematician at the

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Mathematical Institute in Oxford, England; Basaran; and Sidney R. Nagel, a professor of physics at the University of Chicago.

Drops usually form in air, which has much lower viscosity than liquid. For example, water dripping from a faucet is more viscous than the surrounding air.

If, however, a nozzle is immersed into a sticky liquid like honey or silicone oil, which is thousands of times thicker than water, the water drops form differently than they would in air.

"First of all, the drops take much longer to form," Basaran said.

Moreover, instead of abruptly breaking off, the segment of liquid between the forming drop and the nozzle's tip continues to grow into a narrow thread and eventually becomes much longer than it would if the drop were forming in air.

"In this special case, this region doesn't shrink to a point and break off like it ordinarily would," Basaran said. "Mathematically, we say that it 'remembers' its initial state, which is very unusual."

Rather than separating from the nozzle at a single point, the liquid cuts away in two places: at the point where the drop has formed and at a point closer to the nozzle. The drop falls away, but an extremely thin thread of liquid or gas also separates from the nozzle.

If the liquid contains certain chemicals, the threadlike segment can be quickly solidified by exposing it to "photo-polymerizing" light, creating extremely thin filaments or fibers of uniform thickness.

Researchers were surprised by the potential for practical applications.

"Initially we just thought it was a new scientific discovery, which it is because it violates everything that was known," Basaran said. "This thin thread forms so slowly — which was also unexpected — that you have enough time to solidify it into a filament or wire."

Chemical engineers at Purdue have performed mathematical calculations and computer simulations to explain the phenomenon, and physicists at the University of Chicago have carried out experiments in which they have created fibers less than 100 nanometers wide.

Nano is a prefix meaning one-billionth, so a nanometer is one-billionth of a meter, or roughly the length of 10 hydrogen atoms strung together.

Researchers deduced a mathematical formula that can be used to predict how long and thin the filaments will grow before they break away from the nozzle. The formula is essentially the viscosity of the outside liquid divided by the viscosity of the liquid inside the drop.

This ratio of viscosities has been used experimentally to make filaments of varying lengths and widths. The greater the difference in viscosity, the thinner and longer the filaments become.

"If we make the outer liquid more and more viscous, we can make it quite long," Basaran said. "There is no known limit as to how long and how narrow you can make this. You can just play around with the viscosity ratio.

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"My student at Purdue did the computations that led to the explanation of this phenomenon, and the mathematicians developed a more simplified explanation of what was going on. So it was really a big collaborative effort."

The researchers have been involved in the work for about two years, initially observing the phenomenon in experiments and later developing mathematical explanations.

"At first we couldn't explain it because it contradicted what was known about how drops form," Basaran said.

He said the method might one day be used to make flexible nano-wires out of many types of materials that conduct electricity, including polymers.

Scientists hope to eventually produce wires so thin that their diameter is smaller than the width of an electron's wavelength, which could be used to dramatically alter the flow of electricity and heat. It is possible that other researchers might use such wires to develop a new class of electronics, solid-state refrigerators, air conditioners and power generators.

The research was funded by the U.S. Department of Energy's Basic Energy Sciences program and the National Science Foundation. The ongoing Department of Energy funding is for "basic research," which is carried out with no specific practical applications in mind.

"People should understand the benefits of basic research and how it results in discoveries that were not predicted," Basaran said.

The work is continuing at Purdue, with funding from the Department of Energy and private corporations.

"The type of drop breakup discovered and its potential applications are just one small piece of the 'drop-breakup puzzle,'" Basaran said.

esv/Basaran.nanothreads

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IMAGE CAPTION:

This computer-generated series of images illustrates a surprising discovery about the formation of drops from nozzles such as those in inkjet printers. A team led by researchers at Purdue University and the University of Chicago has shown that the drops form differently when the nozzle is immersed into sticky liquids, such as honey or silicone oil, which have greater viscosity than the drop. As the drop forms, so does a long, thin threadlike attachment. If the drop is made of certain chemicals, this thin thread can be quickly solidified by exposing it, for example, to "photo-polymerizing" light. The method might be used to create fibers, wires and particles only a few nanometers wide, which could have numerous applications, from composite materials to a new class of electronics and pharmaceutical products. (Ron Suryo and Osman Basaran/Purdue University School of Chemical Engineering)

A publication-quality photo is available at ftp://ftp.purdue.edu/pub/uns/basaran.nanothreads.jpeg.

ABSTRACT

Persistence of Memory in Drop Breakup: The Breakdown of Universality

Pankaj Doshi, Itai Cohen, Wendy W. Zhang, Michael Siegel, Peter Howell, Osman A. Basaran, Sidney R. Nagel

A low-viscosity drop breaking apart inside a viscous fluid is encountered when air bubbles, entrained in thick syrup or honey, rise and break apart. Experiments, simulations, and theory show that the breakup under conditions in which the interior viscosity can be neglected produces an exceptional form of singularity. In contrast to previous studies of drop breakup, universality is violated so that the final shape at breakup retains an imprint of the initial and boundary conditions. A finite interior viscosity, no matter how small, cuts off this form of singularity and produces an unexpectedly long and slender thread. If exterior viscosity is large enough, however, the cutoff does not occur because the minimum drop radius reaches subatomic dimensions first.