PHANTOM

2017
CASE STUDY

Capturing Fast-Moving Ferrofluids On The Nanoscale

Juniata College researchers use a Phantom high-speed camera to study the microfluid dynamics of ferrofluids—unique, magnetic particles that have vast implications for future lab-on-a-chip devices.

Ferrofluids look like something out of outer space: pass a magnet over the surface of the liquid, and it begins to reach towards you with its gooey, spiky arms. But ferrofluids are hardly science fiction.

Dr. Yu Gu, Assistant Professor of Physics at Juniata College, leads a team of three undergraduate students in researching how ferrofluid droplets behave inside capillary tubes and other lab-on-a-chip (LOC) environments. Not only are these reactions too small to see; they're also too fast. That's why Gu and her team utilize a Phantom high-speed digital camera in their physics laboratory to capture the behavior of these unique, nanoscale particles.

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Ferrofluids (see sidebar) are colloidal suspensions of nanometer-sized ferromagnetic particles. They have the fluid properties of a liquid but become strongly magnetized like a solid in the presence of a magnetic field. "They're a novel type of fluid," Gu said. "They respond to an external magnetic field—changing viscosity and surface properties depending on what kind of field they're in."

Gu studies ferrofluids in very small volumes. "Think: one-tenth of a human tear," Gu said. The purpose of her research, which is funded by the Research Corporation for Science Advancement, is to learn how ferrofluids behave as they move through capillary tubes at high speeds—an area of research that has vast implications for microfluidics and the development of miniature lab-on-a-chip (LOC) devices (see sidebar). For example, in many current LOC systems, processing small quantities of fluidic samples poses a challenge. Many silicon-based micropumps are too expensive to use in commercialized or disposable LOC devices.

"That's where ferrofluids come in," Gu said. "They have already shown a lot of potential when it comes to fluid handling, pumping and valving in microfluidic systems. They point to the development of a cost-effective, disposable micropump."

Understanding microfluidics, or the manipulation of the flow of very small volumes of fluid within micrometer-sized channels, is critical to developing viable LOC devices, which typically handle fluid volumes of a few hundred nanoliters (10^{-10} m^3). LOC-based devices are a game-changing technology for the life sciences, medicine and global health because it is easier and safer to control the movement, interaction and analysis of small-scale samples.

"All of this plays into what we do in our lab," Gu said. "We're looking to apply what we learn about ferrofluids to lab-on-a-chip technology."

THE SCIENCE BEHIND FERROFLUIDS

Ferrofluids are a combination of iron-oxide particles (usually magnetite or hematite), a liquid carrier and surfactant to prevent clumping. These nanoscale concoctions were first discovered by NASA in the 1960s, as scientists sought new ways to control liquids in outer space. On average, ferrofluid particles have a diameter of only 10 nanometers.

A magnetized ferrofluid gets its distinctive "spiky" shape because of normal-field instability, a phenomenon in which the ferrofluid seeks the most stable shape to minimize the total energy of the system. In the presence of a magnetic field, the ferrofluid is drawn out along the magnetic field lines, resulting in the formation of peaks and valleys. At the same time, the extension of the liquid is resisted by the forces of gravity and surface tension. The formation of the "spikes" lowers the magnetic energy of the system while raising the gravitational and surface-free energies. When these forces are balanced, the ferrofluid achieves its minimum energy configuration.

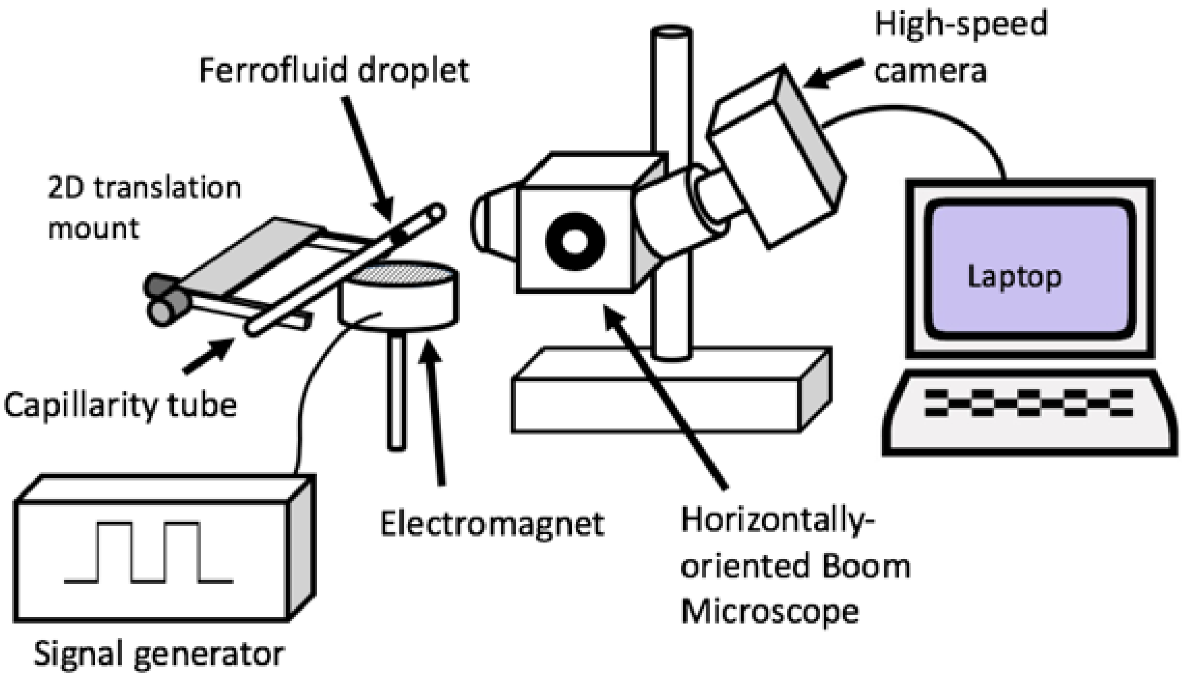
Ferrofluids are used in a range of applications, including semiconductor manufacturing, where they are used to seal hydraulic machinery. They are also frequently used in household loudspeakers to prevent unwanted vibrations.

THE SIGNIFICANCE OF LAB-ON-A-CHIP

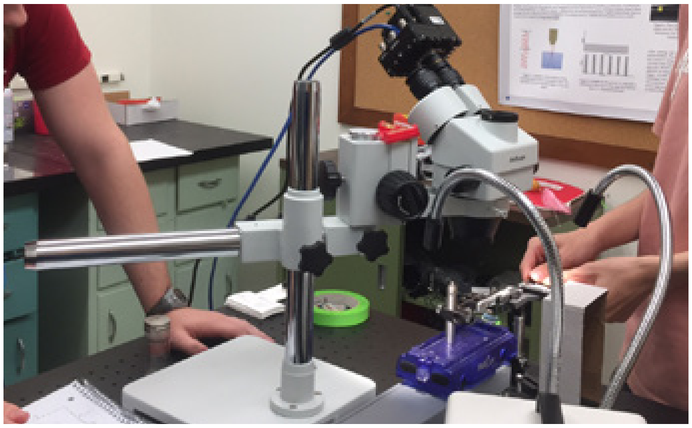
Miniature lab-on-a-chip (LOC) devices carry out operations that normally require laboratory synthesis or chemical analysis for applications in medicine and the life sciences, including High-Throughput Screening (HTS) and medical diagnostics. The circuits themselves range in size from a few millimeters to a few square centimeters.

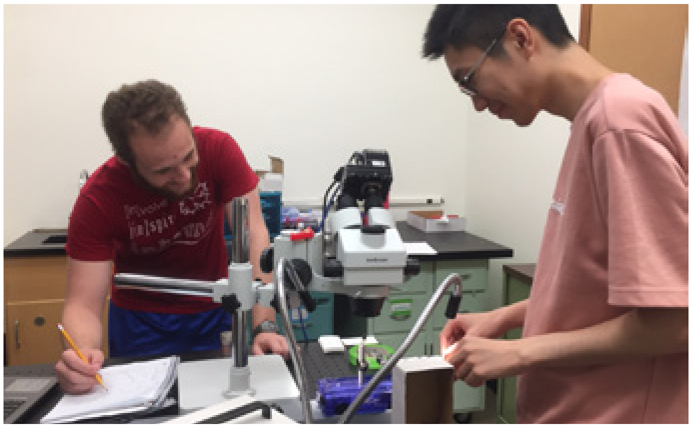
“Here’s how we like to explain lab-on-a-chip,” Gu said. “How nice would it be to get a blood test from a single pin prick, rather than having to stick a needle in your arm, draw the blood and then send the sample away to a lab?”

Despite recent advancements in microfluidics and nanotechnology, as well as the success of many theoretical models and proof-of-concept studies, few LOC devices have been successfully brought to market.



Ferrofluid samples are contained in microcapillary tubing and placed onto an electromagnet. Using the Phantom camera, which is hooked up to a microscope, the team can record how these particles behave in the presence of a magnetic force.





"We have several manuscripts in the pipeline, and our experiments hold a lot of promise," Gu said. "The camera is the star piece of equipment in our physics lab. I can definitely foresee other departments wanting to use it."

CAPTURING THE NANOSCALE

In their physics department lab, Gu and her team utilize a Phantom Miro C110 high-speed camera to image the behavior of ferrofluid droplets moving at high speeds inside capillary tubes and other LOC-type environments. "We want to see what these fluids do when they move quickly," Gu said. "For instance, they change shape, angles—sometimes they even split. These reactions happen very quickly, so the camera is a key piece of equipment for us."

The Miro C110 can record at speeds up to 900 frames-per-second (fps) at full 1280 x 1024 resolution and over 52,400 fps at smaller resolutions. The C110 is also well suited for microscope work. It has small, 5.6-µm pixels that capture detail in magnification applications and is designed with a C-mount that attaches to microscopes. For their experiments, Gu and her students select speeds between 900 and 1,000 fps. Ferrofluid samples are contained in microcapillary tubing—less than one millimeter in diameter—and placed onto an electromagnetic field. The Phantom camera is hooked up to a microscope with the lens pointing towards the side of the tubing. From there, Gu and her students are able to record the behavior of the fast-moving, nanoscale particles in the presence of an induced magnetic force.

"We have several manuscripts in the pipeline, and our experiments hold a lot of promise," Gu said. "The camera is the star piece of equipment in our physics lab. I can definitely foresee other departments wanting to use it."