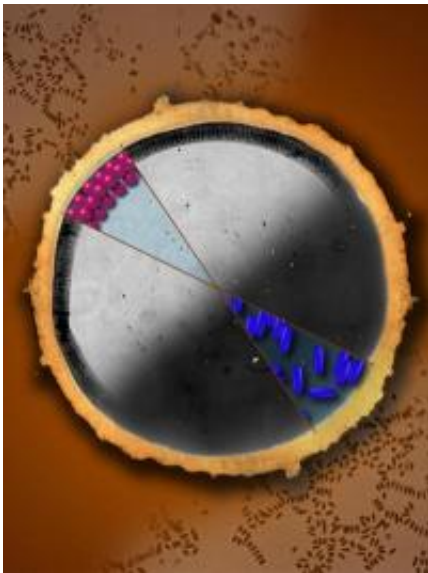


Physicists undo the 'coffee ring effect' (w/ video)

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This illustration represents a how a dried drop would appear if it contained round particles (red) or elongated particles (blue). When a drop of coffee or tea dries, its particles (which are round) leave behind a ring-like stain called the "coffee ring effect" (upper left). But if you change the shape of the particles, the coffee stain behavior changes too. Elongated particles (blue) do not exhibit the coffee ring effect, rather they are deposited across the entire area of the drop, resulting in a uniformly dark stain (lower right). Credit: Felice Macera, University of Pennsylvania

A team of University of Pennsylvania physicists has shown how to disrupt the "coffee ring effect" — the ring-shaped stain of particles leftover after coffee drops evaporate — by changing the particle shape.

The discovery provides new tools for engineers to deposit uniform coatings.

The research was conducted by professor Arjun Yodh, director of the Laboratory for Research on the Structure of Matter; doctoral candidates Peter Yunker and Matthew Lohr; and postdoctoral fellow Tim Still, all of the department of Physics and Astronomy in Penn's School of Arts and Sciences.

Their research will be published in the journal *Nature* on August 18.

"The coffee ring effect is very common in everyday experience," Yunker said. "To avoid it, scientists have gone to great lengths designing paints and inks that produce an even coating upon evaporation. We found that the effect can be eliminated simply by changing the shape of the particle."

The edges of a water drop sitting on a table or a piece of paper, for example, are often "pinned" to the surface. This means that when the water evaporates, the drop can't shrink in circumference but instead flattens out. That flattening motion pushes water and anything suspended in it, such as coffee [particles](#), to its edges. By the time the drop fully evaporates, most of the particles have reached the edge and are deposited on the surface, making a dark ring.

University of Chicago [physicists](#) Sidney Nagel, Thomas Witten and their colleagues wrote an influential paper about this process in 1997, which focused mainly on suspended spherical particles, but it was not until the Yodh team's recent experiments that the surprising role played by suspended particle shape was discovered.

Yodh's team used uniformly sized plastic particles in their experiments. These particles were initially spherical but could be stretched into

varying degrees of eccentricity, to ensure the experiments only tested the effect of the particle's shape on the drying pattern.

The researchers were surprised at how big an effect particle shape had on the drying phenomenon.

"Different particle geometries change the nature of the membrane at the air-water interface," Yodh said. "And that has big consequences."

Spherical particles easily detach from the interface, and they flow past one another easily because the spheres do not substantially deform the air-water interface. Ellipsoid particles, however, cause substantial undulation of the air-water interface that in turn induces very strong attractions between the ellipsoids. Thus the ellipsoids tend to get stuck on the surface, and, while the stuck particles can continue to flow towards the drop's edges during evaporation, they increasingly block each other, creating a traffic jam of particles that eventually covers the drop's surface.

"Once you stretch the spherical particles by about 20 percent," Yunker said, "the particles deposit uniformly."

After experimenting with suspended particle shape, the researchers added a surfactant, essentially soap, into the drops to show that interactions on the drop's surface were responsible for the effect. With the surfactant lowering the drop's surface tension, ellipsoid particles did not get stuck at the interface and flowed freely to the edge.

They also tested drops that had mixtures of both spherical and oblong particles. When the spheres were much smaller than the ellipsoids, the spheres flowed to the edge, but, at a certain size, they became similarly trapped.

"We were thinking it would be useful if you could just sprinkle in a few of these ellipsoid particles to remove the coffee ring effect," Yodh said, "and we found that sometimes this idea works and sometimes it doesn't."

Understanding the impact of particle shape on drop drying could have applications in printing and painting. The principles could also be relevant in biological and medical contexts.

"In many cases, the way we make coatings involves hazardous chemicals," Yunker said. "If you need something that's bio-compatible, it's more difficult."

"There are a lot of situations where you want uniform coatings," he said. "This work will stimulate people to think about new ways of doing it."

Provided by University of Pennsylvania

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