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From charged polymers to life-saving innovations

Whether natural or synthetic, polymers — large molecules made up of repeating units called monomers — exhibit complex structures and properties that make them useful in a wide range of applications. In their soft, nearly liquid biogel form, polymers viewed through an optical microscope resemble a bowl of tangled soft noodles. In that state, they tend to coacervate, or combine, with other polymers — when those polymers carry opposite electrostatic charges.

UC Santa Barbara materials professor and department chair [Omar Saleh](#) has spent decades measuring and characterizing polymer behavior. He recently received a three-year grant of \$441,000 from the National Science Foundation (NSF) to conduct refined experiments designed to better understand the fundamental nature of complex coacervates.

“In this project, we aim to understand how mixtures of charged polymers called *complex coacervates* can form microscopic droplets having unique properties, such as the ability to encapsulate and deliver drugs and act as adhesives,” Saleh said, adding that, while his group is not targeting a specific application or technology, the biological polymers he is focusing on — hyaluronic acid and RNA coacervates — reflect broader interest in applications from drug delivery to cosmetics.

Saleh’s lab is a good place for such research because his team specializes in taking exacting measurements at the nanometer scale. Saleh estimates that his is one of

only 10 labs in the world conducting nanoscale measurements of microgel polymers with custom-built instrumentations.

The team's unique tool, known as magnetic tweezers, is used to measure small changes in polymers under varying forces. "It's a unique, high-precision characterization technique," Saleh said, "in which we use the magnetic field to apply a tiny, well-known, and well-controlled stretching force to the polymer while measuring its extension to within one nanometer of accuracy."

"Other people are also good at this," he added, while acknowledging that he has something of a head start. "I started developing some of the things when I was a postdoc with a group in Paris. We've done pretty well with it over the years, and recently we developed a way to use that instrument to study a particular problem associated with coacervation, which is: how does the conformation of a polymer (i.e., its shape after being pulled on by the tweezers) affect coacervation?"

That granularity is important because one nanometer is a lot smaller than a polymer, which, when stretched, is about 100 to 1,000 times as long as that. "Our one-nanometer accuracy enables us to sense very small changes in the shape of the polymer as it undergoes interactions with other things in the environment," Saleh explained. "We set up a high-precision sensor, which is a stretched polymer, and then something binds to it, and it changes length, and we're able to measure that and, from this precise measurement, quantify in excruciating detail everything the polymer is doing."

On the one hand, polymers in the loosely organized microgel state bind in an atypical way. "It's like a wiggly, sticky ball of noodles," Saleh said. "The fact that it holds together — but not as it would in a typical binding or phase transition to a solid, where everything becomes rigid afterwards — makes the microgel phase physically interesting. It also makes it very hard to measure, because you can't do X-ray crystallography on it, for the simple reason that there is no crystal structure when the polymer is in the semi-liquid state we're talking about."

Still, that little ball of noodles — and the droplets within it — may one day be used to deliver drugs or, because it's very sticky, to serve as an adhesive, perhaps even a surgical glue.

Any such application will require an increased understanding of the fundamental science behind the coacervate state. That is no small challenge. "The 'ball of

noodles' is a very complicated and tricky physical situation, and if we want to engineer it, we need to understand it better," Saleh said. "So what we're going to do in this project is to use our high-resolution measurement technique to understand it better, and that should enable a range of applications in the long run."

There is a lot of promise for what can be done with polymers in this state, he noted. "Certain applications are coming out" that are based mostly on "empirically applying" what is known about the coacervate state. "You can find something that works without having to understand *how* it works," Saleh explained. "And, you can try to make a product that way. And, that's not a bad way to do things; it's very practical. But obviously, from a scientific point of view, it's interesting to try to solve some of the fundamental problems, and it almost always turns out that solving those fundamental problems opens up new applications to do things in a better way."

The research will be buttressed by the work of Mark Stevens, an expert in simulations who works at Sandia National Laboratories. He can simulate what Saleh described as: "the quite novel geometry for the (stretching) experiment, creating a decent facsimile of the experimental geometry, and we can draw insights from what the simulation shows. That will be very important for this experiment because we're not just carrying out the same kind of experiment that has been done for years, or buying an instrument that does this well-established procedure. For us, it's all quite new, so we have to develop new interpretation techniques, and the simulation will help with that."

Saleh hopes that the work will reveal "the role of polymer configuration, ionic strength, temperature and polycation architecture in determining phase behavior, and establish a new physical framework for understanding tension-modulated complex coacervation."

In describing the project, he highlighted two important aspects: first, that he will be able to hire a PhD student to support the effort, contributing greatly to a student's skilled training, and second, that NSF continues to fund important research.

"This is a very specific niche of STEM work and a specialized technique, but the training is really broad in the sense that if you can build and use this instrument, you can build and use a lot of instruments," Saleh said. "There are many fundamentals of quantitative science and polymer science that this person is going to learn that will have a huge application in a variety of fields."

Regarding NSF funding, Saleh added, “NSF support is so important to the American economy. Without funding, research doesn’t happen, and we need to be reminded of this. The funds will directly support a graduate student who will get trained in these advanced methods and then go out and join the economy and push our technological capabilities and the scientific establishment. That is what we do.”

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