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Cooled-down plasma could help detect elusive nanoparticles responsible for so many health hazards

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“If we can get plasma out of a glass or metal enclosure and keep it from heating up, that’s when we could do some really interesting stuff,” says Jeffrey Hopwood. Credit: Kelvin Ma

We're awash in tiny nanoparticles. Some are components of car and truck exhaust; others are manufactured intentionally for products ranging from cosmetics to electronic devices. Most are only a few nanometers in size—roughly a thousand times thinner than a human hair.

No matter what they're made of, these particles' tiny size can create health hazards. Airborne nanoparticles can be drawn into the tiniest nooks and crannies of our lungs and pass directly into the bloodstream—even through cell membranes—damaging tissue and causing widespread inflammation. The smaller a particle is, the tougher it is to detect.

"Air quality reports tend to look at bigger particles like diesel soot or other things you can see. But detecting really small particles is much harder," says Jeff Hopwood, a professor of electrical and computer engineering at Tufts who is trying to develop a better way to spot nanoparticles in the air we breathe.

Existing detectors, he says, use a radioactive substance to sense airborne particles. As the individual grains of nanoscale material pass through a radioactive field, they take on a negative charge so that an electrical sensor can record their presence.

"The problem with this method is that the radioactive source is itself dangerous," Hopwood says, "and so it's not a really practical method of looking for nanoparticles."

He's trying something completely different. Instead of relying on radioactivity to find and count nanoparticles, Hopwood thinks it's possible to use something that's safer but far more exotic—plasma.

Shrinking It Down

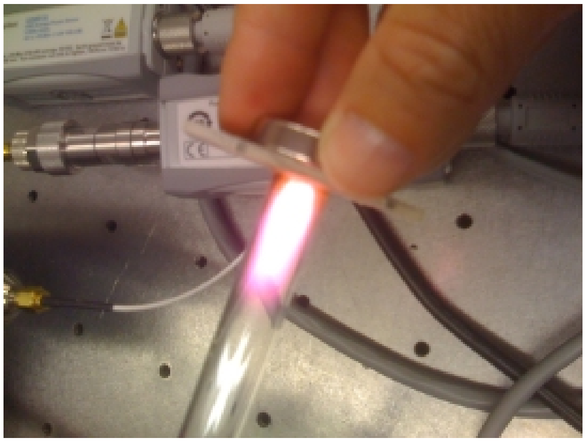
Plasma, he notes, is the "fourth state" of matter, and differs from the other three—solids, liquids and gases—in a few unique ways.

In solids, molecules are packed together tightly, with little room to move about. In liquids, they're looser and more energetic, able to float past each other freely. In gases, they are freer still; they dance and twirl, bounce into each other and careen apart, forming ethereal clouds of matter. Energize these molecules even more, and something singular happens. They begin to move so quickly that they shed their electrons and form a plasma—a chaotic, glowing cloud of loose electrons and ionized atoms.

We encounter plasmas every day, in electrical devices like TVs and fluorescent lights. Plasmas' free-floating electrons allow them to conduct electricity, react to magnetic fields and imbue any object that enters them with an electrical charge—even diminutive nanoparticles. That trait makes plasma a terrific ingredient in a nanoparticle counter.

The only problem, Hopwood says, is that when a plasma normally forms in the atmosphere, it's not so easy to manipulate. "At atmospheric pressure, you usually get a very hot, potentially destructive plasma," he says. As electrons are energized, they begin to move more rapidly and collide into gas molecules in the air around them, which heats the air up to thousands of degrees. "Lightning, electrical sparks—those are all examples of hot plasmas," he says.

But it is possible to make plasma cooler and easier to work with, usually by creating the plasma inside a vacuum chamber and removing air molecules that would otherwise generate heat. These plasmas are sealed away, such as they are in fluorescent lights, neon signs and the pixels that make up plasma displays in TVs.



A microscopic plasma formed by a microwave circuit board creates a large plume of plasma inside a glass tube. Credit: Jeff Hopwood

Hopwood wants to break these boundaries—literally—and find ways to create cool plasmas under normal, atmospheric conditions.

"If we can get plasma out of a glass or metal enclosure and keep it from heating up, that's when we could do some really interesting stuff," he says.

Once released from the confines of a controlled environment, Hopwood says, cool plasma could be used to not only detect nanoparticles but disinfect surfaces in hospitals, destroying microbes that pass through its electrical field. It could help clean up pollution by breaking down volatile compounds like benzene and toluene, often found in petroleum products. Cool plasma could even help detect harmful gases that might be present in labs or industrial sites.

"You could essentially make something like a tricorder—that handheld sensor they use all the time on Star Trek. It could tell you at a glance, 'Is the air here safe to breathe?'"

To create a plasma outside of a vacuum chamber—and keep it cool enough to handle—you need to make it small. Really, really small.

Creating Cold Lightning

In his lab, Hopwood is trying to create "microplasmas," tiny balls of energetic gas that are less than a millimeter wide, or about the thickness of a credit card. At that scale, he says, the physics of plasma starts to change, and it becomes possible to maintain a low temperature under atmospheric conditions.

While he says it's still not clear exactly why that's the case, he thinks one reason may have to do with the small surface area of microplasmas in relation to their size.

Think of it this way: if you heat up a BB pellet, it's relatively easy to cool it off again. If you heat up a bowling ball, though, it will take far longer to cool. Because it's much bigger than a BB, its center tends to stay hot longer.

But size isn't the only factor in keeping plasmas cool. A small circuit-board spark—itself a type of plasma—is still hot enough to destroy sensitive electronics. So Hopwood is working on ways to effectively "freeze" that spark at the moment of its generation, creating a tiny, cool plasma in the process.

"The spark naturally wants to become hot. Its natural progression is to go to a lightning-like hot plasma state. To create a cool plasma, you have to engineer something that says 'stop, don't do that,'" he says. "We're basically creating cold lightning, in a sense."

Finding the Right Rhythm

Hopwood heads to a bulbous metal chamber on a workbench in his lab. He gestures excitedly to the window in the side of the device. Inside is a homemade circuit board the size of a book of matches. A dot of glowing blue light emanates from its surface—a tiny ball of plasma, glimmering right there in the open.

Hopwood has drawers full of these little circuit boards. They don't look like much—each with a few small microchips hand-soldered onto its edges and a flat copper ring the width of a quarter etched onto its surface. The copper forms a perfect circle, interrupted only by a minuscule gap on one side.

This configuration is the secret to making tiny plasmas, he says. The chips attached to the board, which normally power antennas in cell phones, feed microwave energy into the ring at a specific frequency. If the ring is just the right size, it will begin to resonate, or "vibrate" electrically at the same frequency, almost like a tuning fork. In the process, it causes a blast of electrical energy to surge across the gap, creating a spark.

As soon as that spark forms, it changes the electrical properties of the circuit, which reduces the spark's powers and keeps it from reaching its normally hot, destructive state. If done correctly, a few billion times per second, a cold plasma will appear in the spark's place.

"The trick is to add enough power to generate the early moments of a spark, but pull the power back before it gets too hot. By repeating that process indefinitely, we effectively stop the spark in its tracks and create a tiny, cool plasma," Hopwood says. "You just have to find the right rhythm, or right frequency."

He's quick to note that the work is in its nascent stages. It will be a long time before he's snaring and analyzing nanoparticles. Hopwood and his colleagues are still learning about what makes the circuits tick and how they can improve the plasmas they're creating. This is the fun part—when it comes to understanding electronics, Hopwood likes to dig deep, answering questions not only about circuit design but about the fundamental physics of each component.

"With plasma, that seems to be an unending question," he says, eyes gleaming. "The physics are really, really complicated. But I've always been driven by deep physical understanding. Okay, so you can do something—but how does it work? What's the overlying principle? I guess in that way I've always kind of gone down the rabbit hole."

Provided by Tufts University