Dry ice, the unsung hero of the COVID-19 vaccine rollout, explained

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Robert Levis dumped chunks of a whitish substance into a beaker of water, and immediately the liquid began frothing and churning like a sorcerer's potion, spewing plumes of fog across the table of his office at Temple University.

"It looks like the water is boiling," said Levis, a chemistry professor.

Just the opposite. The fog was not steam, but water droplets that had frozen—thanks to a blast of subzero cold from the whitish substance: dry ice.

Formally known as solid carbon dioxide, dry ice gets its nickname from a chemical property that is fairly described as sublime. It does not melt, but sublimates—going straight from solid to gas, with no messy liquid involved. And because the solid form has a temperature of negative 109 degrees Fahrenheit, it cools everything nearby like a champ.

Such as vaccines. As we've been hearing for months, the COVID-19 shots made by Pfizer Inc. and BioNTech SE require particular attention to the "cold chain"—keeping the vials at ultra-low temperatures on the trip from factory to clinic so the RNA-based product does not degrade. Regular freezer temperatures are OK for two weeks before usage, but for long-term storage and transport, the required range is between -112 and -76 degrees: a perfect fit for dry ice.

Levis illustrated the material's cool properties recently with a series of demonstrations. There were popping balloons. Food coloring. A toy gun that shot soap bubbles!

His real job involves research on such cutting-edge topics as using lasers to measure the chemical "markers" of brain injury, but who says university types can't have a little fun? Levis, who also lectures on the chemistry of making wine, is a big proponent of using everyday phenomena as teaching tools.

And dry ice, used for such varied purposes as making ice cream, blasting graffiti off walls, and creating "fog" for special effects, is about as everyday as you can get.

Why it's dry

Simply put, molecules of carbon dioxide do not cling to each other well.

To understand why, let's start with water. Molecules of water are "polar," meaning they are slightly positive on one end (the hydrogen atoms in H2O) and slightly negative on the other (the oxygen). Opposites attract, so the molecules stick together fairly well. This is why water molecules tend to cluster in little beads on a drinking glass or car windshield, a process called cohesion.

But molecules of carbon dioxide (CO_2) have an oxygen atom (the negative part) on both ends, with carbon in the middle. No attraction between the end of one molecule and the next. The result: it doesn't take much for molecules of carbon dioxide to skedaddle apart from each other. Once you get higher than negative 109 degrees, whoosh! The molecules spring apart into the gaseous phase, without pausing in the liquid form.

At room temperature, it happens in a hurry.

To demonstrate, Levis placed chunks of dry ice in a plastic bottle and attached a balloon over the top. He then did the same for another bottle with cubes of what he called "water ice"—that is, frozen water, not the summertime Philadelphia treat. (Note to those who might try this on their own: Wear protective gloves to handle the dry ice, and do so in a ventilated area.)

Almost immediately, the balloon on the dry-ice bottle began to inflate, as the solid chunks sublimated into carbon dioxide gas. In just a few minutes, bang! No more balloon.

"Ha ha!" he chortled. "Worth the wait."

Yet in the other bottle, the regular ice simply melted into water. Small amounts were evaporating, but not enough to see any impact. The balloon remained limp.

How it is made

Whether a substance is solid, liquid, or gas depends on more than temperature. Another factor is pressure. If the pressure is high enough, even carbon dioxide can be compressed from a gas into its liquid phase.

In fact, that's how dry ice is made, said Rich Gottwald, president of the Compressed Gas Association, an industry trade group. (Among its members is Radnor-based Airgas, one of the leading U.S. producers of dry ice.)

First, carbon dioxide gas is captured as a byproduct from various industrial processes such as making ethanol. It is then compressed into a liquid inside a metal tank. When a special kind of release valve is opened, the sudden pressure drop allows the liquid to escape rapidly as a gas. The temperature plummets accordingly, so much so that the gas immediately freezes into white flakes: dry ice.

The same principle is used in air conditioning and refrigeration, as coolant fluid is compressed then allowed to expand into gaseous form, over and over in a cycle. But other substances are used for that purpose, not carbon dioxide. There is no "ice" phase, just liquid and gas. As chemistry students learn, every substance behaves differently in response to various combinations of temperature and pressure.

Members of the compressed-gas trade group produce 35,000 tons of carbon dioxide every day in the U.S. and Canada, of which 16% is made into dry ice, Gottwald said. To accommodate the added demand for shipping the vaccines, companies have boosted dry-ice production by an estimated 5%—which works out to less than 1% of the overall carbon dioxide production total. No shortages have been reported.

Heavy stuff

Final fun fact. This has nothing to do with its usefulness in shipping vaccines, but carbon dioxide is denser than air. To demonstrate, Levis placed chunks of dry ice in a plastic bin and allowed it to start sublimating into an invisible layer of gas.

He then used a toy gun to shoot soap bubbles across the top. The bubbles were filled with air, and ordinarily would have sunk to the floor due to the weight of the thin film of soap. But in the chemist's demo, the air-filled bubbles remained aloft, floating atop the layer of denser carbon dioxide beneath.

"It's just like a helium balloon," he said.

Carbon dioxide also is a greenhouse gas, meaning it plays a role in climate change, but that's a subject for another day. And dry ice doesn't really contribute to the problem, since it is made from CO_2 that is being produced anyway.

Back to the topic of the moment: keeping vaccines cold. A few other substances could get the job done, such as liquid nitrogen. But that would be overkill, as its temperature is negative 320 degrees.

You also could cool regular ice down far enough to keep the vaccines cold. But that would be less efficient than simply using dry ice itself, said Levis, who is senior associate dean of the Temple's College of Science and Technology. Besides, when regular ice melts, the result (surprise!) is water. The vaccine labels would come off.

So as you navigate the cumbersome process to sign up for vaccination, it makes sense to chill in at least one respect. Dry ice is on the case.

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