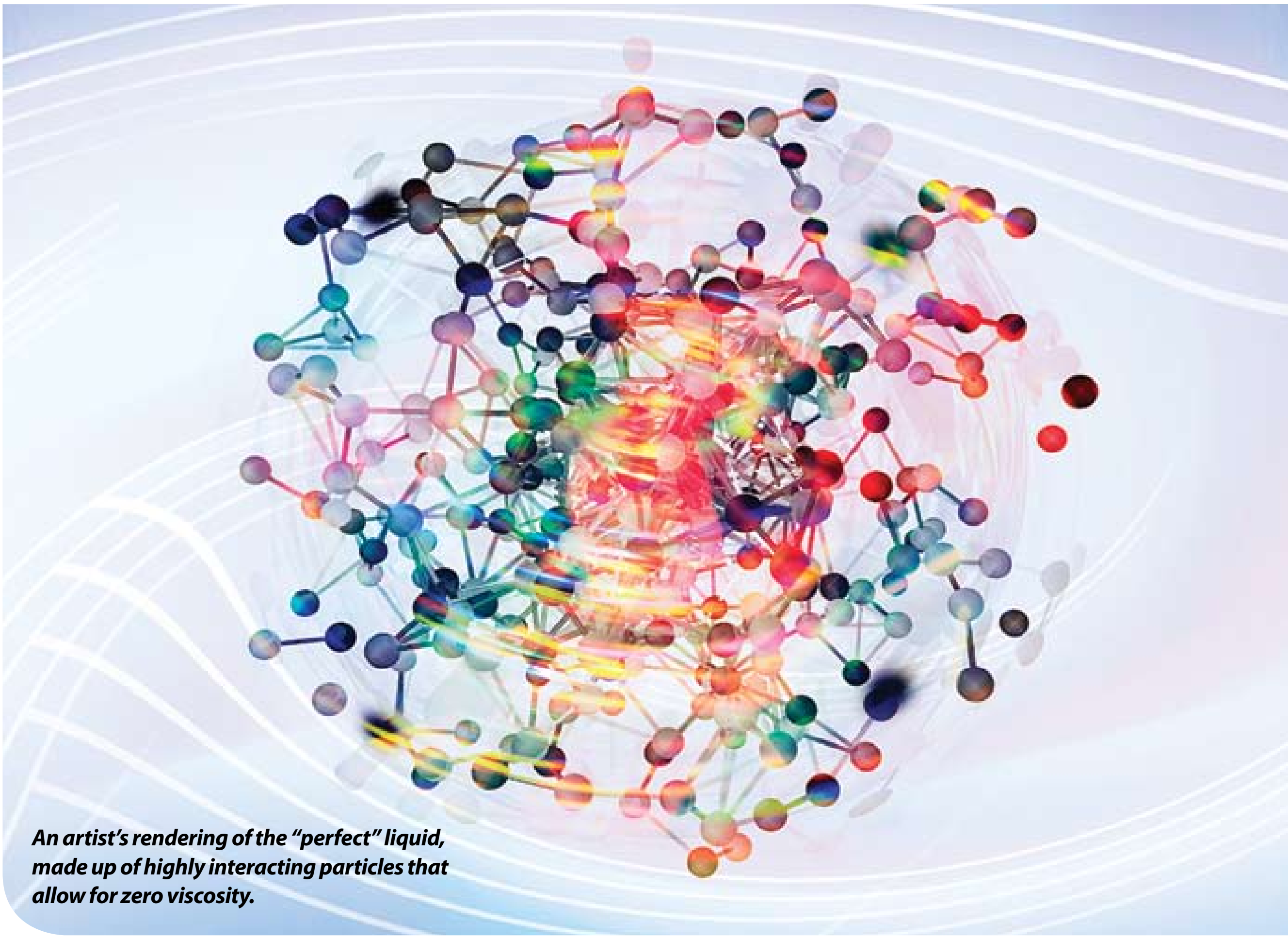

An artist's rendering of the "perfect" liquid, made up of highly interacting particles that allow for zero viscosity.

A Liquid Beginning

Physicists simulating conditions right after the big bang have found that the universe started off as a "perfect" liquid. How does this change our understanding of the properties of matter?

All matter as we know it was created in the first few seconds of the big bang. But scientists don't know exactly how this happened. When researchers tested the leading theory by smashing gold ions into each other at nearly the speed of light in 2004, rather than creating conditions that mirrored a perfect gas, as predicted, the ions formed a nearly perfect liquid. Now physicists are amping up particle accelerators to use this surprising result to test string theory.

A First Glimpse

By the early 1930s, scientists knew that atoms consisted of a cloud of electrons and a nucleus made of smaller particles, called protons and neutrons. But it wasn't until the early 1970s that a new theory, quantum chromodynamics, described how these particles were bound together in atomic nuclei. This theory also predicted that under extreme conditions, protons and neutrons would melt, freeing smaller particles inside them called quarks and gluons. The freed particles were expected to form quark-gluon plasma (QGP), a state of matter physicists believe to have existed microseconds after the big bang. It is only in the past decade, however, that new, higher-energy particle accelerators have created such plasmas for study.

The first hints of QGP emerged in 2000 at CERN, the European center for particle physics near Geneva, Switzerland. But the relatively low initial temperatures and short life span of

What Is a Perfect Liquid?

The matter formed at the RHIC is the closest thing to a perfect liquid ever observed. The thousands of particles emerging from a single collision of two gold nuclei move with a high degree of coordination, unlike normal liquids, in which individual molecules move randomly. The particles behave almost like a theoretical "perfect" fluid—a fluid with a high degree of interaction among particles and zero viscosity.

plasma made it difficult to study the possible QGP directly. It wasn't until 2004 that scientists at Brookhaven National Laboratory were able to use the more powerful Relativistic Heavy Ion Collider (RHIC) to detect QGP and measure its properties.

The RHIC, in operation since 2001, produces high-energy collisions of gold-ion beams traveling at near light speed within a 2.4-mile-long tunnel. The collisions yield temperatures of approximately 2 trillion degrees Celsius (3.6 trillion degrees Fahrenheit), recreating conditions found within about 10 microseconds of the big bang, when quarks and gluons still roamed free.

But the QGP detected in 2004 didn't behave exactly as physicists had predicted. According to Steve Vigdor, the associate lab director for nuclear and particle physics at Brookhaven, before the RHIC fired up, it was expected that particles in the QGP would barely interact, like atoms in a so-called ideal gas. Scientists found instead that the thousands of particles emerging from a single collision of two gold nuclei seemed to show a high degree of coordination of movement. In fact, QGP seemed to have all the properties of a nearly "perfect" liquid, one with extremely low viscosity (a perfect liquid would have zero viscosity). "Such ideal liquid flow requires exceedingly strong interactions among the constituents—they need to remain in essentially instantaneous contact with one another," Vigdor adds. This behavior is in marked contrast to the predictions of quantum chromodynamics.

Understanding the Liquid

The discrepancy may be explained by string theory, an approach that models subatomic particles as tiny, vibrating stringlike entities. String theory has existed since 1970, but only as a mathematical construct; physicists have long been searching for some experimental confirmation. Now it seems like the RHIC's findings could be explained by an aspect of string theory that links the theories of strongly interacting particles and gravity. This has encouraged string theorists to try to predict other properties of QGP found at the RHIC, since testing these predictions would be a great way to validate the theory.

The RHIC's 2.4-mile-long concentric rings are made up of 1,740 superconducting magnets mounted end to end.

Scientists at the RHIC have discovered that some of QGP's characteristics, like its viscosity, seem to be fairly close to those predicted by string theory. The primary goal for the next decade is to procure more detailed measurements of QGP. But before they can do so, they will need more plasma samples, meaning more collisions per experiment.

An upgraded RHIC, dubbed the RHIC II, aims to increase collision rates 10-fold by next year. The improved collider will allow scientists to correct imperfections in the atom beam in real time. These imperfections will be measured at one point on the accelerator, and this information will be sent by a fiber-optic network or microwave link to a location ahead of the ion beam. Here, electric fields will automatically refocus the beam to prevent ions from missing each other on their collision course.

In the future, another upgrade will add a high-energy electron beam to the RHIC, which will make it the world's only electron-heavy-ion collider. Smashing heavy nuclei with electrons will give scientists a precise image of the nucleus and a better look at the strong force holding quarks and gluons together.

Any theory that seeks to explain the formation of the early universe must account for the different collision properties observed at different energies. So studying the characteristics of QGP using multiple accelerators can help develop a more comprehensive theory. Heavy-ion collisions at CERN's Large Hadron Collider (LHC) will produce matter at temperatures perhaps two to three times as high as those seen at the RHIC. Even though this matter is still unlikely to be at the ideal gas state originally predicted by quantum chromodynamics, it may be closer than that observed at the RHIC. And GSI, the German research center for heavy-ion physics, is currently building the Facility for Antiproton and Ion Research (FAIR). Scheduled to begin operating in 2016, FAIR will measure the properties of nuclear matter at lower temperatures than either the RHIC or the LHC.

The combination of the RHIC, the LHC and FAIR could provide the most complete picture yet of the contents of the nucleus and resolve many of the current mysteries surrounding quark-gluon plasma, bringing us closer to understanding the birth of our universe and the very nature of matter in it. ■

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