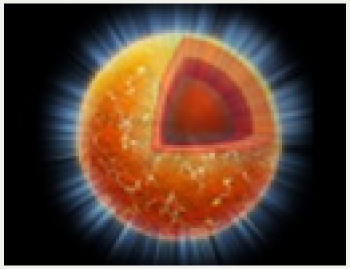
Neutron Stars

When massive stars eventually run out of fuel and collapse, the extreme pressure inside the star squeezes electrons and protons together until they merge to form neutrons. This process eventually forms an immensely dense object with a core made mostly of neutrons—a neutron star. Neutron stars are so dense that a teaspoon of material from the star would weigh about six billion tons!

NASA research teams have been studying a neutron star located at the center of a cloud of gas 11,000 light years away. The neutron star and the gas cloud, called Cassiopeia A, are the remnants of a supernova explosion. NASA believes that the core of this neutron star contains a superfluid.



Artist concept of a neutron star within supernova remnant Cassiopeia A. Illustration credit: NASA/CXC/M.Weiss

Data from NASA's Chandra X-ray Observatory showed a rapid decrease in the temperature of this neutron star. This suggests that a superconducting material is in the core of the star, allowing heat to be transferred out quickly. (A superconductor is a material that transfers heat and electricity with no resistance.) When superfluids are made of charged particles, they are also superconductors. In this case, any remaining (positively charged) protons in the star's core form the superfluid/superconductor. Still, it is surprising that these protons are in superfluid form at tremendously high temperatures, whereas superfluids generally form on earth at temperatures near absolute zero!

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Is it a bird?
Is it a plane?

No, it's Super Fluid!

HELPING TO FURTHER

PUBLIC UNDERSTANDING

OF PHYSICS CONCEPTS

Superfluids!

What would you think if your orange juice started creeping up the sides of your glass and spilling out onto the table? That would be pretty creepy, right? Well, superfluids can do just that. They appear to defy gravity, traveling upwards along surfaces, escaping out of bowls and cups. They can even leak out of tiny molecule-sized holes!

Superfluids are so "super," because they have zero viscosity. That is, nothing resists the flow of a superfluid. To understand the term "viscosity," consider a jar of molasses. Molasses has a very high viscosity. It is thick and moves slowly. Orange juice has a much lower viscosity than molasses, but it still won't spontaneously shoot up the straw when you're trying to drink it! Superfluids can though, because they have absolutely no viscosity.

Superfluid helium can climb up the sides of a dish and escape through tiny cracks. Image Credit: VUERQEX, public domain

This may seem like magic, but if you imagine yourself at the level of individual atoms in a superfluid, you can see what is happening. All of the atoms in a superfluid are in what is called the same "quantum state." That is, every atom has the same momentum, which means they all move together synchronously. The entire fluid, then, functions as one particle. This allows the fluid to flow without any friction or resistance.

For example, liquid helium becomes a superfluid when it is cooled to temperatures below -452 degrees Fahrenheit. (This is really cold! For comparison, the average winter temperature at the North Pole is about -30 degrees Fahrenheit.) Liquids will naturally coat the surface of their container because of the slight attraction between atoms, but superfluid helium contains a unique surface wave, which pushes an extremely thin film of the liquid up the sides of the container. The fluid then coats the entire surface and can even escape from the container once it reaches the top!

In the picture below, a superfluid is in a container along with a smaller bowl sitting in the pool of superfluid. The superfluid outside the bowl creeps up the sides of the bowl and then spills into it. The superfluid will continue to do this until the level of fluid inside the bowl matches the level outside. Notice that the superfluid has also coated the walls of the larger container in which it is held. If this wasn't a sealed container, the fluid would spill up over the container's sides and escape.

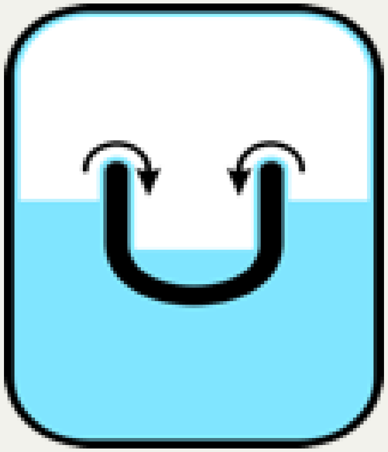

Image Credit: Design – Aarchiba; SVG rendering – Júlio Reis, Wikimedia Commons

Superfluids also conduct heat extremely well, much like a superconductor. When heat is introduced to the system, it is transmitted extremely quickly throughout the fluid. In fact, the heat is transmitted so quickly that thermal waves may be produced. These waves are sometime referred to as "second sound." They are similar to sound waves in some ways, but do not involve variations in pressure.

Still, superfluids are capable of transmitting regular sound waves as well. Physicists found this perplexing—why can superfluids transmit both thermal waves and regular sound waves? To explain the presence of both of these waves, scientists came up with the "two-fluid model." According to this theory, superfluids are made up of a mixture of atoms that are synchronized in the same quantum state and regular atoms that are not synchronized. The synchronized atoms allow for thermal waves to be present, while the "normal" atoms allow for sound waves to be present. The percentage of synchronized atoms increases as the temperature approaches absolute zero, theoretically the lowest temperature possible. Thus, only at absolute zero, are all of the atoms in a superfluid in the same quantum state.

Actually, this synchronization of quantum states creates a whole new state of matter called the Bose-Einstein Condensate, which means that solids, liquids, gases, and plasmas are not the only states of matter in the universe! At the University of Colorado, Boulder, Physicists Cornell and Wieman proved the existence of this new state of matter. They trapped about a million rubidium atoms in the same quantum state and then observed the atoms acting as a collective unit.