Physicists show that superfluid light is possible

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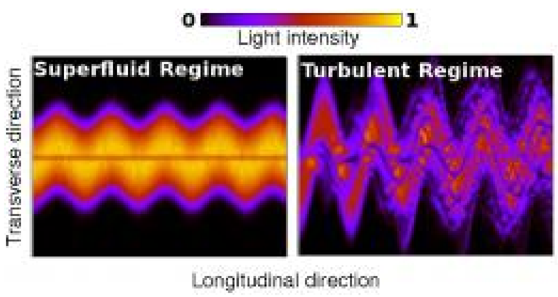

These images show the difference between the superfluid regime (left) of light and the turbulent regime (right), which is above the critical velocity. Image credit: Leboeuf and Moulieras.

(PhysOrg.com) -- Superfluidity – the phase of matter that enables a fluid to move up the sides of its container – has been known about since the 1930s. Since then, superfluidity has become a prime example of how quantum effects can become visible on the macroscopic scale under certain conditions. Although physicists have previously considered the possibility of superfluid light, their results have been inconclusive until now. In a new study, physicists from France have theoretically shown that superfluid motion of light is indeed possible, and have proposed an experiment to observe the phenomena.

In their study published in a recent issue of Physical Review Letters, Patricio Leboeuf and Simon Moulieras from the University Paris-Sud and CNRS explain that superfluidity is the ability of a fluid to move with zero dissipation or viscosity. A fluid behaves like a superfluid only under a certain critical velocity; above this critical velocity, superfluidity disappears. Most commonly demonstrated in liquid helium, superfluidity occurs when the helium is cooled and some helium atoms have reached their lowest possible energy. At this point, these atoms' quantum wave functions begin to overlap so that they form a Bose-Einstein condensate, in which all the atoms behave as one large atom, and their quantum nature is manifested on the macroscopic scale.

Previously, investigations of the superfluid motion of light have not revealed clear evidence of the existence of a superfluid critical velocity. Although some recent experiments have observed superfluidity related to light, these experiments did not use photons, but a composite particle, called a polariton, which is a mixture of a photon and an exciton.

In this study, Leboeuf and Moulieras have shown that a superfluid critical velocity does exist in a nonlinear medium. They explain how superfluid light can be observed in an array of waveguides. From a dynamical point of view, light propagating through a nonlinear medium is formally equivalent to a Bose gas of interacting massive particles. Light can travel straight along the waveguides in the longitudinal direction, or it can tunnel between adjacent guides in the transverse direction. The benefit of this set-up is that it allows the scientists to engineer different characteristics of the array and control the light's flow.

The physicists were specifically interested in what happens to a light pulse as it travels through the array at different velocities in the presence of a defect. If the light is scattered by the defect, it means dissipative processes have occurred. If the light pulse moves through the defect without changing its shape (i.e., without losing collectivity), there is no dissipation and the light has superfluid motion. Through their calculations, the physicists showed that, for certain low velocities, the transverse motion of light is superfluid with zero dissipation. When the velocity increases, dissipative processes occur that destroy the collectivity of the light's oscillations, and superfluidity breaks down.

In the future, the physicists plan to further investigate additional details of superfluid light, such as how it relates to an underlying quantum theory of light and how it is connected to Bose-Einstein condensation. They predict that superfluid motion is a general property of light that exists in a variety of scenarios, and is not limited to the waveguide array proposed here. Superfluid light could also have applications in light transport optimization.

“One straightforward implication is related to transport in the presence of noise,” Leboeuf said. “Such a noise is expected to be present generically, since any material has imperfections and impurities. The impurities are responsible for the scattering of light. In the superfluid regime, we expect a light pulse to be able to propagate through a noisy medium without being affected or scattered (perfect transmission).”

Leboeuf and Moulieras plan to perform their proposed experiment and are discussing the opportunity with experimental groups at the Laboratoire de Photonique et de Nanostructures (LPN) at Marcoussis, France. However, the scientists said that superfluid light is not likely to have any strange effect analogous to a superfluid flowing up a container.

“The most basic 'strange' quantum effect that light shows related to superfluidity is, as shown in our article, dissipationless motion,” Moulieras said. “Another, though more indirect or spectacular, effect is related to quantized vortices, which were observed in laser patterns propagating through nonlinear media. Concerning other possibilities, such as fluid motion up the walls of a container, they are related, for atoms, to the forces between these atoms and a substrate, and the balance between capillary, gravity and viscous forces. We do not see a straightforward application of these concepts to photons, and therefore do not expect them for light."

More information: Patricio Leboeuf and Simon Moulieras. "Superfluid Motion of Light." *Physical Review Letters* 105, 163904 (2010). DOI: 10.1103/PhysRevLett.105.163904