Critical velocities and stationary waves in a two-component supersonic superfluid

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The properties of a two-component superfluid system are described by the three-velocity hydrodynamics. Since superfluid components can flow without friction, superfluid velocities of the components may differ from each other and from the velocity of the normal component. The question on critical velocities in the three-velocity hydrodynamics requires special consideration because in general case the spectrum of the excitations cannot be found from the Galilean transformation. One of the experimental methods to determine critical velocities for trapped ultracold gases consists in the observation of density excitations induced by some object moving through the condensate. Since the Bogolyubov spectrum has a dispersion a motion of an object through a superfluid system can lead to an occurrence of stationary waves.

Properties of stationary waves in a flow of a two-component quasi-two-dimensional Bose-Einstein condensate past an obstacle are studied here. It is shown that stationary waves arise when the Landau criterium is broken. It yields a joint condition on absolute values of the superfluid velocities of the components and on the angle between their directions. At the same time, the existence of stationary waves is restricted from above by the condition that relative velocity of the components does not exceed some critical value (otherwise a spatial separation of the components takes place). It is shown that several qualitatively different stationary wave patterns are possible. If the velocities are the same, (one) two sets of waves can appear when the velocities exceed the phase velocity of the lower (higher) hydrodynamic mode. If only one component moves then only one set of waves can emerge. If the velocities are equal in modulus and the angle between the velocities is close to $\pi/2$, two or tree sets of interfered stationary waves can arise. The two-dimensional images of the total density and relative density oscillations in the stationary wave pattern are obtained. It is established that in most cases the waves are visible in total density images as well as in relative density images, but the relative density images are more contrast.