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VORTEX-RING FORMATION BY NEGATIVE IONS IN He II UNDER PRESSURE*

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It was previously shown that at temperatures $\geq 0.36°K$ and pressures >12 atm negative ions in He II could be accelerated until they emitted rotons at velocities of about 50 m/sec. We find that at temperatures $\leq 0.3°K$ negative ions produce only vortex rings at pressures up to 16 atm.

At temperatures $\geq 0.36°K$ negative ions in superfluid helium produce quantized vortex rings at low pressures, but surprisingly at pressures above 12 atm they can be accelerated to the Landau critical velocity of ~50 m/sec at which they produce rotons.[1,2] We have found that at temperatures $\leq 0.3°K$ negative ions, like positive ions, produce only vortex rings, even at 16 atm and in the presence of an excess of He^3 impurities.

Our experimental cell, which was initially intended for other experiments, contained a Po^{210} source of ~5 μCi, several regions separated by grids, and a collector. In the present experiments the charge carriers were accelerated in a 6-mm long space adjacent to the radioactive source. Their velocity was then measured by gating in a second 6-mm long space in an adaptation of the method analyzed in detail by Tanner.[3] The cell was refrigerated by a He^3/He^4 dilution refrigerator.[4]

At a pressure of 16 atm (the limit of our apparatus) and $T \approx 0.5°K$, our results are completely consistent with those of Rayfield: Vortex rings comprise only a minor fraction of the total current drawn from the source. However, as the temperature is reduced, rings comprise an increasing fraction of the total current, until at all $T \leq 0.3°K$ the current consists of vortex rings only. At $T \sim 0.05°K$ the current consists entirely of rings even after the addition of 3×10^{-5} mole fraction He^3, although this causes significant energy losses for the rings.

It has been suggested that the creation of a vortex ring and its capture of the ion is a discontinuour process.[5,6] In such a case, conservation of energy and momentum require that the ion of mass m^* reach a critical velocity $v_c = P_0/2m^* + E_0/P_0$, in which P_0 is the impulse of the ring[7] and E_0 its energy. As pointed out by Pines,[6] this requires a v_c greater than the Landau critical velocity for creation of rotons. He attributes the difficulty to the use of improper expressions for E_0 and P_0. However, Rayfield[8] interprets his experimental evidence as showing that, at least in the presence of He^3 scattering, the formation of the ring from the positive ion is a continuous process. We feel that our results also support the model of ring formation extended over some time, since they show that the critical velocity which a negative ion must achieve before demonstrating a ringlike dispersion relation is temperature dependent as well as pressure dependent. These results suggest that negative ions under pressure at $T \geq 0.36°K$ undergo sufficient scattering by phonons and rotons so that during acceleration of the ion the formation of a quantized ring is perturbed, and many of the ions can reach the Landau critical velocity. At $T < 0.3°K$, however, rings can always be formed at a negative-ion velocity less than the roton critical velocity, as is always the case for positive ions. A He^3 concentration of 3×10^{-5} mole fraction does not provide enough scattering to prevent the formation of rings.

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