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VORTEX-RING CREATION BY NEGATIVE IONS IN DILUTE MIXTURES OF He^3-He^4 †

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We describe an experiment which indicates that the addition of He^3 impurities to superfluid helium has a pronounced effect on the velocity at which negative ions produce vorticity (vortex rings). The He^3 impurities have no effect, however, on the creation of vorticity by positive ions.

In earlier work[1] the creation of vorticity by positive ions was studied in the presence of He^3 impurities. The ion–vortex-ring transition was found to be smoothly connected with no discontinuity in the drift velocity of the ion complex when vortex rings are produced. The corresponding velocity necessary for positive ions to produce vortex rings is found to remain unchanged. If negative ions are studied in the presence of He^3 impurities one would also expect a smoothly connected curve when vorticity is produced. This is indeed the result, provided some pressure is applied to the liquid thereby increasing the negative-ion mobility. The interesting feature of the negative-ion results, however, is a reduced critical velocity for vortex-ring formation in the presence of He^3 impurities.

The upper curve in Fig. 1 shows the critical velocity V_c for vortex-ring creation by negative ions in pure He^4. The helium used in obtaining this curve was passed through a millipore filter as described previously.[2] In the earlier experiments[2] the initial rise in the critical velocity V_c for vortex-ring production by negative ions seemed to agree with a relation of the form $V_c \propto 1/R$ where R is the radius of the negative-ion bubble. The decreasing region of the curve was associated with roton creation by the negative ion under pressure. Presumably in this region the velocity necessary for vortex-ring creation by the negative ion is greater than the velocity necessary for roton emission. The lower curve in Fig. 1 shows the results when a dilute He^3-He^4 mixture is formed (atomic He^3 concentration equal to 1.25×10^{-4}). The temperature of the dilute mixture was near 0.3°K and comparatively

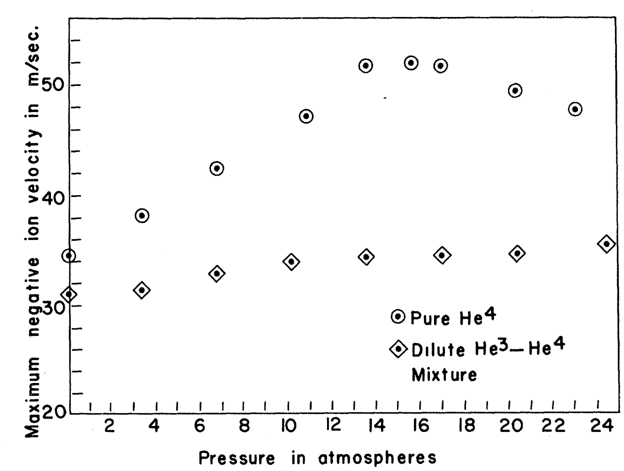

FIG. 1. Critical velocity necessary for vortex-ring formation by negative ions in pure helium (upper curve) and in a dilute mixture of He^3-He^4 (atomic He^3 concentration 1.25×10^{-4}).

little thermal quasiparticle scattering was present. The critical velocity for vortex-ring production is now observed to show very little pressure dependence and indeed is observed to lie below the velocity necessary for roton emission. This result with the negative ion is in strong contrast to that of the positive ion where the vortex-ring creation velocity is found to be independent of temperature, pressure, and He^3 concentration. If the atomic concentration of He^3 is increased to 4.4×10^{-4}, the lower curve shown in Fig. 1 is not changed at 0.3°K. However, if the temperature is increased to about 0.6°K, the critical velocity at 21 atm increases to approximately 3800 cm/sec. This temperature dependence is more pronounced at lower concentrations. For a concentration of 1.32×10^{-5}, a temperature of 0.66°K, and a pressure of 21.1 atm, the creation velocity is raised to 4600 cm/sec,[3] and seems to be limited by roton creation rather than vortex-ring formation. Below this pressure and at the same temperature and He^3 concentration, vortex rings are formed. The results of these experiments indicate that the critical velocity for vortex-ring formation by negative ions depends on the relative concentration of thermally excited quasiparticles and He^3 impurities.

One possible reason for the anomalous behavior of the negative ion relative to that of the positive ion would be an alteration of the negative-ion structure due to the presence of He^3 impurities. This altered structure should be observable by studying the mobility of the negative ion. Meyer and Reif[4,5] have studied the mobility of the negative ion as a function of pressure and He^3 concentration. Surprisingly, the mobility of the negative ion is about equal to that of the positive ion above 10 atm. With a dilute mixture of He^3 in the superfluid at zero pressure and 0.5°K the mobility of the negative ion is reported to be about one-tenth that of the positive ion. Recent measurements of the size of the negative ion indicate it has a radius of about 16 to 20 Å.[6-8] The size of the positive ion has been estimated to be about 6 Å.[9] The mobility of both positive and negative ions was studied in the present series of experiments under pressure at low temperature ($T\simeq0.3$°K) in the presence of He^3 impurities. The ratio of positive-ion mobility to negative-ion mobility varied from about 5 to 2.5 as the pressure was varied from 0 to 24 atm. In particular at higher pressures the negative-ion mobility was found to be considerably less than that of the positive ion in contrast to the thermal quasiparticle scattering data of Meyer and Reif. The mobility of the positive ion was found to be independent of pressure.

Although the mobility data indicate that the structure of the negative ion could be influenced by the presence of He^3 impurities, other experiments such as ion trapping on vortex lines[6,7] and optical absorption[8] would be most useful.

It is difficult to see how the structure of the negative ion could remain unchanged and yet have the velocity for vortex-ring creation vary with He^3 concentration while keeping the positive-ion critical velocity independent of concentration.

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