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EFFECT OF $^4$He ON POSITIVE-ION MOBILITY IN NORMAL LIQUID $^3$He

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Résumé. On a constaté que la mobilité des ions positifs dans du $^3$He très pur est presque proportionnelle à $\ln(1/T)$ entre 3 mK et ~ 100 mK, en accord avec les récents résultats théoriques. L'addition de faibles quantités de $^4$He abaisse considérablement cette mobilité à températures élevées et basses températures, peut conduire à l'existence simultanée de plusieurs espèces ioniques.

Abstract. We have found that the mobility of positive ions in very pure $^3$He is nearly proportional to $\ln(1/T)$ from 3 mK to ~ 100 mK as predicted by recent theory. The addition of small amounts of $^4$He, however, greatly reduces the mobility at higher temperatures and can lead to the simultaneous existence of several ion species at low temperatures.

It is generally accepted that the positive-ion species in pure $^3$He (or pure $^4$He) consists of a $\text{He}_2^+$ molecule surrounded by a cluster of He atoms which are polarized and held to the ion by the electric field of the positive charge, /1,2/. Typically, the radius of such a cluster will be 6-8 Å and, because of the high electrostrictive pressures, the He surrounding the ion will actually be solid—hence the description of the positive-ion species as a "snowball". The mobility of the ion is a measure of its interaction with the quasiparticles in the liquid. If the ion behaved as a free particle in these scattering interactions, then the mobility would be expected to increase as $T^{-2}$ at very low temperatures /3,4/. However, the ion does not recoil like a free particle at low temperatures and recent calculations /5/ have shown that, in this case, the mobility should be proportional to $\ln(1/T)$.

In order to generate ions at very low temperatures with a minimum of heating, we use a field emission tip which is pulsed to a high voltage when ions are needed. The mobility of the ions is determined by measuring their time of flight in a uniform electric field. Our lowest temperatures are obtained by the adiabatic demagnetization of cerium magnesium nitrate (CMN) which is in contact with our $^3$He sample. Details of our technique can be found elsewhere /6,7/.

Results of our measurements at low pressures (some of which have appeared previously /6/), are shown in figure 1.

Fig. 1: Positive-ion mobility for $P = 60$ torr in the presence of small amounts of $^4$He.

The data for the purest $^3$He (30 ppm $^4$He) fairly closely follow the expected $\ln(1/T)$ behaviour from the lowest temperatures up to ~ 300 mK. By comparing our data with his circulation, Bowley /5/ deduces that our ion radius is 8 Å. The most striking phenomenon shown in this figure is the sharp drop in mobility for moderate $^4$He concentrations when the temperature goes above 50-80 mK. The mobility then remains much lower than

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$^4$Work performed under the auspices of the U.S. Department of Energy.
the pure \(^3\)He data until the temperature reaches 500 mK where the curves come together again. Since this lower mobility must almost certainly be due to a larger ion radius, we interpret the results as evidence for a layer of \(^4\)He having condensed onto the surface of the \(^3\)He snowball. Sluckin /8/ has carried out a detailed analysis of this phenomenon, taking into account the influence of the strong polarization potential of the positive ion core, and has predicted that for a \(^4\)He concentration of 300 ppm, the layer of \(^4\)He condensed on the ion would bring the ion radius up to 13 \(\AA\). Assuming that the mobility at 60 mK is inversely proportional to the cross sectional area of the ion, the observed drop in the mobility at this temperature would correspond to an increase in ion radius from 8 \(\AA\) to 11 \(\AA\). This is in reasonable agreement with the prediction. The reason the \(^4\)He condenses onto the ion so dramatically near 60 mK is presumably associated with the fact that the \(^4\)He solubility is very rapidly increasing at this temperature and \(^4\)He that had been absorbed onto our powdered CMN or had phase-separated out of solution, will redissolve in the \(^3\)He. When the \(^4\)He in the bulk liquid reaches a certain level, the ion will be able to acquire its extra \(^4\)He layer in a transit time. At 60 mK the \(^4\)He solubility is \(\approx 1\) ppm /9/.

At the highest concentrations 3000 ppm and 10,000 ppm the mobility is considerably different. For 3000 ppm the mobility below 15 mK is much less than in pure \(^3\)He and is relatively temperature independent. For 10,000 ppm we see no signals at all below 20 mK. It is likely that these results at high \(^4\)He film on the field emission tip. Perhaps this allows the ions to be created with a large \(^4\)He layer already on them.

Figure 2 shows our data at 20 bar. These data are essentially similar to the low pressure data except for the observation at low temperatures of multiple ion species for the higher \(^4\)He concentrations. Similar results have also been observed by Alexander et al /10/. The existence of several distinct species means that there are several stable radii for the \(^4\)He layer.

![Figure 2: Positive-ion mobility for P = 20 bar in the presence of small amounts of \(^4\)He.](image)

Although it is tempting to interpret these species as due to one layer of \(^4\)He atoms, two layers, etc., estimates of the radii of such layers suggest that the change in mobility from one species to another would be much larger than is observed. Evidently the nature of the \(^4\)He layer on the snowball is somewhat subtle and there is need for much more experimental and theoretical study of this effect.

References

/8/ Sluckin, T. J., (to be published).