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CHANGE OF THE MOBILITY OF POSITIVE IONS IN ROTATING He II

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In two previous communications[1,2] the results of experiments on the influence of rotation on the motion of ions in superfluid helium have been reported. The apparatus used consisted of a diode; the emitting electrode is plated with ^{210}Po, which emits α-particles of 5.3 MeV. These particles intensely ionize the liquid in a very thin layer adjacent to the source. The current passing through the diode is measured as a function of the applied potential. It was shown that the ionic current is decreased by rotation when the current is perpendicular to the rotational axis and remains unchanged if parallel to it. A quite different sensitivity of this effect between positive and negative ions was shown, the latter exhibiting a much larger current decrease. Furthermore, the research was oriented mainly toward an investigation of negative currents moving perpendicularly to the rotational axis. The apparatus had cylindrical symmetry, the two electrodes consisting of two concentric cylinders. An attempt to treat the problem in a more quantitative way was made, by experimentally achieving the condition of completely space charge limited current, defined by having the electric field $E = 0$ at the emitter. In this case a simple relation exists between the applied voltage V, the current i, and the mobility μ

$$i = \alpha\mu V^2 \tag{1}$$

where α is a geometrical constant. This situation has been successfully used to measure the mobility of helium ions.[3,4] It has been shown that, while in the absence of rotation the i *vs.* V^2 plots are straight lines in agreement with equation (1), in the presence of rotation they exhibit a curvature. This leads one to believe that the mechanism of interaction between negative ions and vorticity is not of the same nature as that between ions and the normal helium excitations, i.e., it is not a simple scattering mechanism, which would only change the slope of the straight line. An attempt was made to suggest a mechanism for the trapping of negative ions by the vorticity. A rough evaluation was made, considering the trapped ions as a fixed space charge and assuming this to be the only effective mechanism responsible for the decrease in current. The results give some indication of the order of magnitude of the fixed space charge (10^6 to 10^7 ions/cm^3) and a reasonable voltage and angular velocity dependence: The fixed space charge density increases with increasing voltage and angular velocity, and in some cases there is some evidence of saturation for both. The temperature dependence indicates that the phenomenon is connected with the superfluid fraction of the liquid.

In this paper, we present the extension of our measurements of completely space charge limited currents to the case of positive ions. Figure 1 shows the comparison of an i *vs.* V^2 plot for positive and negative ions with and without rotation.

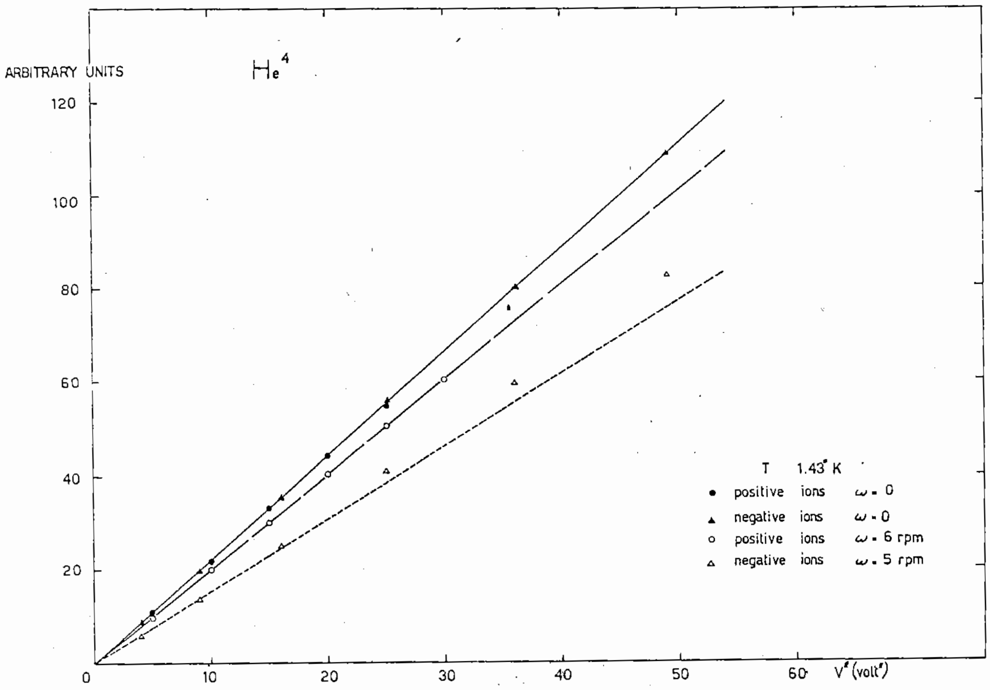

Fig. 1. Plot of the ionic current in liquid ^{4}He *vs.* the square of the applied potential for positive and negative ions with and without rotation. The values of the positive currents have been normalized so as to have the positive and negative curves coincide in the absence of rotation: ●, positive ions, $\omega = 0$; ▲, negative ions, $\omega = 0$; ○, positive ions, $\omega = 6$ rpm; and △, negative ions, $\omega = 5$ rpm.

Since the currents are proportional to the mobilities, and the positive and negative mobilities are very different at the same temperature, a normalization has been necessary in order to make the two nonrotating currents, for positive and negative ions, coincide. A constant average factor has been chosen and all the experimental values of the positive currents, with and without rotation, have been multiplied by this factor. From Fig. 1 one can deduce the following:

1. While for positive currents in rotation the plot is a straight line, this is not true for negative currents in rotation. This allows us to say that for positive ions the effect of rotation can be interpreted in terms of a decrease of mobility, i.e., increase in the density of scattering centers.
2. One of the conditions for equation (1) to hold is that the scattering centers are uniformly distributed. Thus, having a straight line also in the presence of rotation is an indication that vorticity is uniformly distributed.
3. There is a larger decrease in current for negative ions than for positive. (Notice that, for the case of positive ions, a larger angular velocity has been used, 6 instead of 5 rpm, which gives more strength to our statement.) In this respect, we want to point out that the small ratio of the rotation-induced changes of the positive and negative currents (~ 3 times) in Fig. 1 is not in contradiction with the factor (~ 50 times) found by Careri *et al.*[2] In that case we were referring to a current region far from complete space charge limitation. There the current is more weakly related to the mobility and presumably is more sensitive to the presence of a fixed

space charge. Thus, the different ratio of effects in the two current regions for positive and negative ions is a further proof in favor of our hypothesis: change of mobility for positive ions, trapping for negative ions.

We have measured the change of mobility due to rotation for positive ions as a function of the angular velocity ω, the temperature T, and the geometrical parameters. We interpret the results in terms of the equation

$$\frac{1}{\mu_{\mathrm{tot}}} = \frac{1}{\mu_0} + \frac{1}{\mu_\omega}$$

where μ_{tot} is the mobility measured in the presence of rotation, μ_0 is the corresponding mobility without rotation, and μ_ω is the mobility due only to the new scattering centers created by rotation. From the measured values of μ_{tot} and μ_0, we can thus deduce values of μ_ω. Assuming to a first approximation that the density of the additional scattering centers increases linearly with ω, we would have

$$\mu_\omega \omega = \text{constant} \tag{2}$$

Thus we plotted μ_ω^{-1} *vs.* ω; Figure 2 is the result of the measurements performed

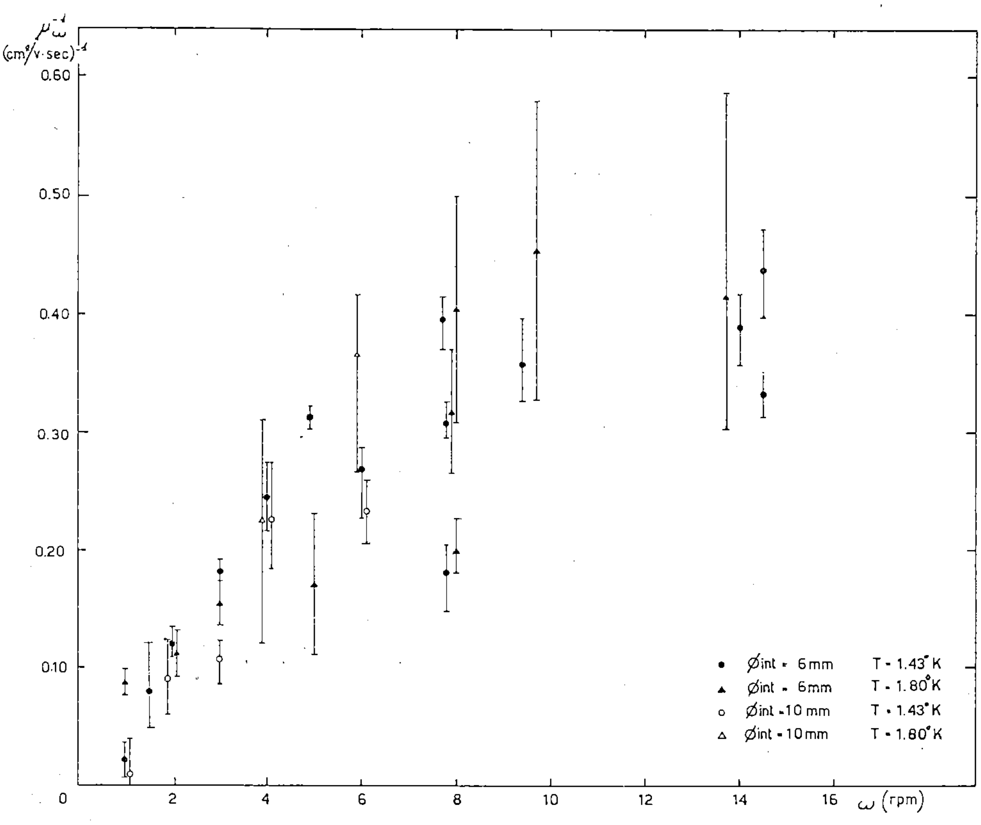

Fig. 2. Plot of the inverse of the mobility μ_ω due to the scattering centers created by the rotation for positive ions in liquid ^{4}He as a function of the angular velocity. The four sets of points correspond to different experimental conditions: ●, $T = 1.43$°K, $\phi_{\mathrm{int}} = 6$ mm (diameter of the internal electrode); ▲, $T = 1.80$°K, $\phi_{\mathrm{int}} = 6$ mm; ○, T = 1.43°K, $\phi_{\mathrm{int}} = 10$ mm; and △, T = 1.80°K, $\phi_{\mathrm{int}} = 10$ mm.

up to now. There are four sets of experimental points, taken at two temperatures (1.43° and 1.80°K) and with two different buckets (ϕ_{int}, diameter of the internal electrode, detector = 6 and 10 mm; ϕ_{ext}, diameter of the external electrode, emitter = 20 mm for both). It is worth while to make a few remarks about Fig. 2.

1. The effects being smaller for positive ions, the errors are larger, and for this reason better statistics are desirable. Only one set of data ($\phi_{\mathrm{int}} = 6$ mm, $T = 1.43$°K) has several measurements for low angular velocities: The experimental points of this set at 1, 2, 3, and 5 rpm are each a weighted average of more measurements taken in different runs and are more consistent with each other. The errors quoted in Fig. 2 are not statistical errors (except for the few cases quoted above). They represent a measurement of the uncertainty with which the slope of the i *vs.* V^2 lines (see Fig. 1) can be evaluated. The slope and its error have been calculated with the help of an electronic computer.

2. In spite of the large band occupied by the experimental points, there seems to be a linear dependence between μ_{ω}^{-1} and ω at low values of ω, in agreement with equation (2).

3. Within the precision of the measurements, there does not seem to be any dependence on temperature, nor on geometrical conditions. The latter could be interpreted as a further indication in favor of the uniform distribution of vorticity.

4. Looking at the most consistent set of points ($\phi_{\mathrm{int}} = 6$ mm, $T = 1.43$°K, $1 \leqslant \omega \leqslant 5$ rpm), the best fit straight line through the experimental points seems to cut the ω axis for $\omega > 0$, thus indicating the existence of a threshold.

To conclude, it seems that the current changes produced by rotation on positive ions, though smaller than for negative ions, can be explained in a more straightforward manner and can perhaps afford useful information on the character of vorticity. Other measurements will be performed, with the aim of decreasing errors and thus reaching more convincing conclusions about the dependence of the mobility changes on angular velocity, temperature, and geometrical parameters.

References

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