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G. Careri, W. D. McCormick, F. Scaramuzzi: IONS IN ROTATING LIQUID HELIUM II.

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IONS IN ROTATING LIQUID HELIUM II

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We have measured the voltage-current characteristics for a beam of thermal helium ions passing through rotating helium II. It has been found that the rotating helium is strongly anisotropic only to the passage of the negative ion: when the current was parallel to the axis of rotation its value for a given applied voltage was independent of whether or not the helium was rotating; when the current was perpendicular to the rotational axis, however, it was strongly attenuated during rotation, the decrease depending on the rotational velocity, the applied voltage and the temperature. This anisotropy is undoubtedly of the same origin as that observed by Vinen and Hall 1) with second sound and we believe that our results also support the Feynman 2)-Onsager 3) vortex line theory of rotation of superfluid helium.

The three types of rotating bucket used were all cylindrically symmetric; their sections in a plane including the rotational axis and in a plane at right angle with it are shown in fig. 2. The buckets were all electrical diodes, having a Po^{210} alpha source deposited on one of their electrodes which produced a thin highly ionized layer in the liquid helium. This layer acted as the ion source, a potential difference between the electrodes drawing out ions of the appropriate sign. For low applied voltages the current is space charge limited and, for simple planar and cylindrical geometries (buckets A and C), may be shown 4) to be proportional to the ionic mobility and to the square of the applied voltage. Using the known values for the mobility 5-7) this relationship has been checked for bucket C in the non-rotating state at different temperatures and found to hold true.

The buckets were rotated at various angular velocities from 1 to 60 revolutions per minute. On starting or stopping the rotation, transient variations of the current lasting several minutes were observed. These effects were presumably due to the setting in motion or stopping of the normal fluid and will not be further discussed in this note.

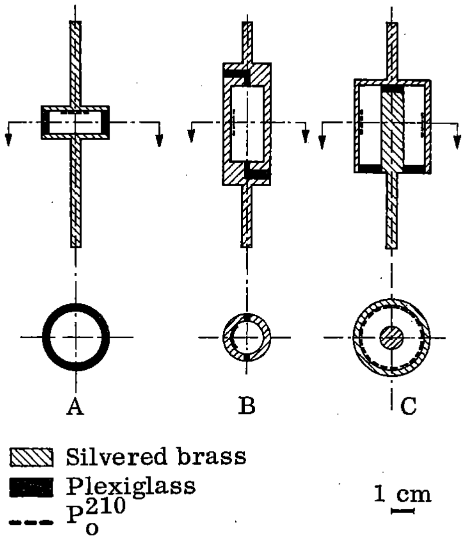

Fig. 1. The sections of the three types of rotating bucket in a plane including the rotational axis (top) and in a plane perpendicular to it (bottom). The dotted lines show the Po^{210} source. In bucket A the ions move parallel to the axis of rotation, in buckets B and C they move at right angles to it.

Bucket A, in which the ions move parallel to the axis of rotation showed no effect of rotation on the current with ions of either sign. In buckets B and C the ions moved at right angle to the rotational axis and rotation was found to attenuate a current carried by negative ions while there was no noticeable effect on the positive ions. Bucket B served only as a control to ensure that the effects observed in the electrically much simpler C did not depend on the toroidal geometry. Hereafter the discussion will be confined entirely to the behaviour of negative ion currents in bucket C.

Fig. 2 shows a typical recorder trace of the current during rotation; the applied voltage was - 5 volt, the temperature was 1.37°K and the an-

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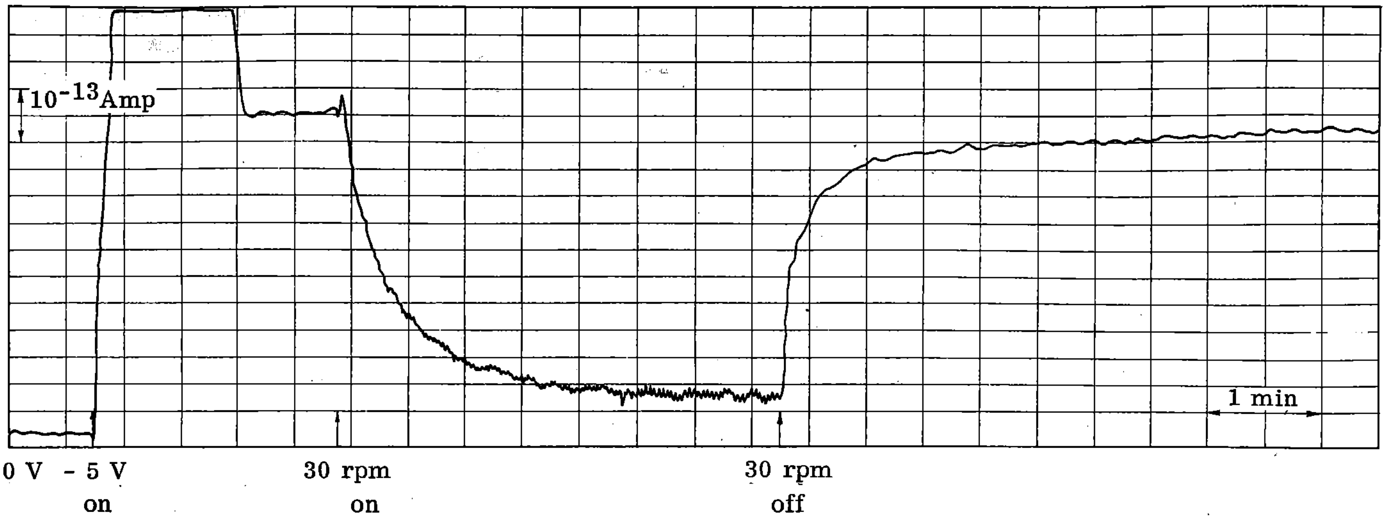

Fig. 2. A typical recorder trace of the negative current as a function of time during a complete cycle of rotation. At the beginning no field exists between the electrodes, then - 5 volt are applied and the induction brings the current out of scale. When the current reaches its stationary value, a rotation of 30 rpm is applied and the current rapidly decreases to roughly 10% of its original value. When the rotation is stopped, the current approaches again the original value. The temperature was 1.37°K.

gular velocity was ω = 30 rpm. It may be seen that when rotation is started the current decreases rather quickly to a small fraction of its initial value. On occasion, to ensure that this is not a transient effect, the rotation has been continued and the current observed to remain constant for periods as long as three hours. When rotation is stopped the current returns to its original value in a time which is strongly temperature dependent, varying from a few minutes near the lambda-point to more than an hour at the lowest temperature reached, $T = 0.9$°K.

Fig. 3 shows plots of the current divided by the mobility versus the voltage squared at the temperature of 1.80°K for the bucket both stationary and rotating at 10 rpm. The straight line is the theoretical expression assuming complete space charge limiting and it may be seen that this describes the situation in the stationary bucket very well. The curve shown for an angular velocity of 10 rpm is typical, curves for higher and lower angular velocities being similar in shape and lying respectively below and above it. At high temperatures the decrease in current becomes smaller and the characteristic approaches the straight line for $\omega = 0$, the difference disappearing at the lambda-point. The effect is roughly proportional to the superfluid fraction but we do not yet have enough data to establish the quantitative relationship.

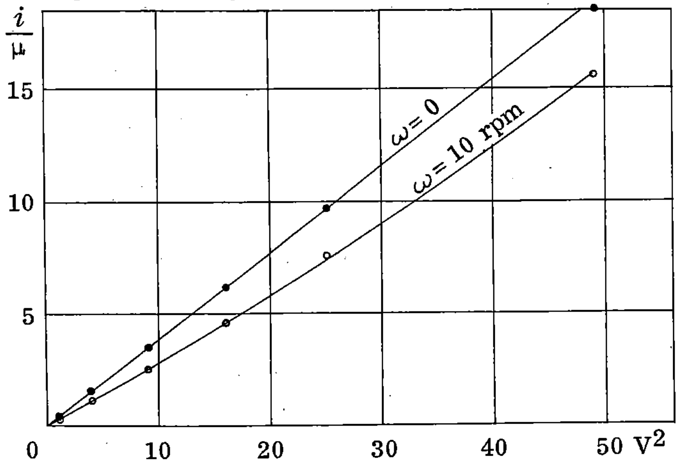

Fig. 3. Plot of the current i divided by the mobility μ of the negative ions versus the voltage V squared, for the bucket stationary (black circles) and rotating at 10 rpm (white circles) at the temperature of 1.80°K; i is in amp. 10^{11}; μ in cm^2/volt· sec, V in volt.

The fact that the current against voltage squared characteristic is not a straight line for the rotating helium shows that the decrease in current cannot be described simply by a decrease in the ionic mobility caused by the addition of new scattering centers. The same conclusion is reached when the temperature dependence of the effect is considered in the light of the temperature dependence of the mobility [5-7].

The only possible explanation for the observed effects caused by rotation seems to lie in the establishment of "traps" in the rotating helium, that is, a certain number of preferred positions in which the ions would be trapped and withheld from the general drift motion. The mean time for which an ion is trapped must be at least of the order of the time taken for an ion to drift from one electrode to the other, a very long time on a molecular scale. This is a well-known problem in semiconductors and the solution of Poisson's equation with fixed space charges in plane geometry has been obtained by Skockley and Prim [8]. Solutions for the same problem with cylindrical geometry have been obtained by Ghizzetti and Gross [9]. The value of the fixed space charge number density n, calculated

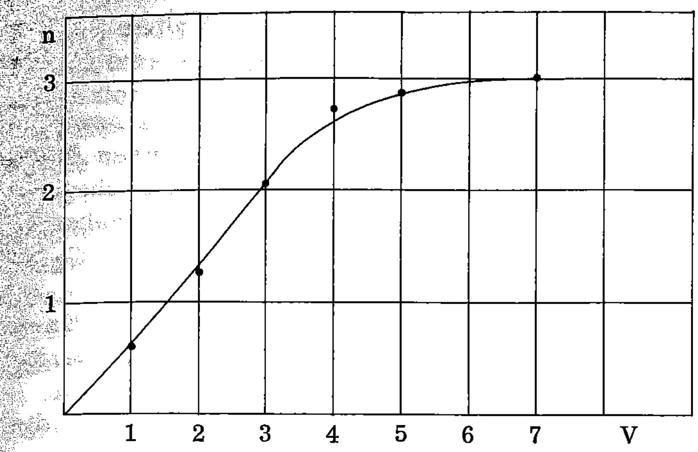

Fig. 4. Plot of the fixed space charge number density n versus the applied voltage. The fixed space charge number density values (in 10^6 ions/cm^3) have been calculated for the experimental points at 10 rpm showed in fig. 3.

for each of the experimental points at 10 rpm of fig. 3 is shown in fig. 4 as a function of the applied voltage. As the voltage increases, the ionic current increases as well and *n* seems to be going into saturation, to a value of nearly 3 × 10^6 ions/cm^3, because of the increase of the ionic density of the beam which makes it easier to fill the empty traps.

It has been observed 10,11) that a reduction in negative ion current similar to that observed here is caused in wide channels filled with helium II by the appearence of turbulence. Vinen 12) has suggested that turbulence in wide channels might be a tangled mass of vortex lines and Onsager 13) observed that if the negative helium ion were an electron trapped in a bubble 14) created by its high zero-point energy, the low density core of a vortex line might very well be effective in trapping it. We thus adopt the Onsager-Feynman theory of rotating superfluid helium, and suggest that the negative ion traps whose existence we have inferred from the experiments are in fact the vortex line cores and that the saturation value of *n* is closely related to the number density of the vortical lines.

These experiments have been performed at the Cryogenic Laboratory of the "Laboratori Nazionali del CNEN, Frascati (Roma)". Further experiments in regard to the temperature and angular velocity dependence are in progress in the hope of confirming the conclusions expressed above in more quantitative form.

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MAGNETISIERUNGSKURVE EINES EINACHSIGEN FERROMAGNETISCHEN EINKRISTALLS IM AXIALEN MAGNETFELD

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1. In der Arbeit 1) (siehe auch 2)) wurde ein quantentheoretisches Rechenverfahren zur Ermittlung der magnetischen Strukturen ferromagnetischer Einkristalle angegeben, das sich auf eine entsprechende Minimalisierung des (angenäherten) Hamiltonoperatormittelwertes in einer bestimmten Klasse von Quantenzuständen stützt. Dieses Verfahren wurde mit Erfolg auf den Fall eines quader-