Mobility of negative and positive ions in liquid and gaseous Helium at 4.5 K under different pressures.

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Helium at 4.5K and different pressures 0.01-0.7 MPa was excited using a corona discharge for both negative and positive high voltages. The range of pressures allowed us to realize both gaseous and liquid states. Mobility of negative and positive charged carriers was calculated using the current-voltage measurements. The mobility is low due to localization of electrons and positive ions in macroscopic bubbles (electrons and negative ions) and snowballs of solid helium (positive ions). The localization of carriers was observe both in liquid and in gaseous Helium.

The corona discharge is a simple method to inject electrons, negative and positive ions in a dense media such as liquid Helium. The discharge has been realized near a point electrode with µm radius stressed by kV voltage. The corona current (exceeded 100 nA) was measured, the current-voltage dependence gave the information about mobility of charge carriers created by the corona.

Measurements have been carried out in normal He at the temperature of T=4.5 K under different pressures. An increasing of pressure at fixed temperature allow us to change the termodynamic state of Helium from gaseous state (P < 0.129 MPa) to liquid state (P > 0.129 MPa), where 0.129 MPa is the boiling pressure at 4.5 K, Figs. 1.

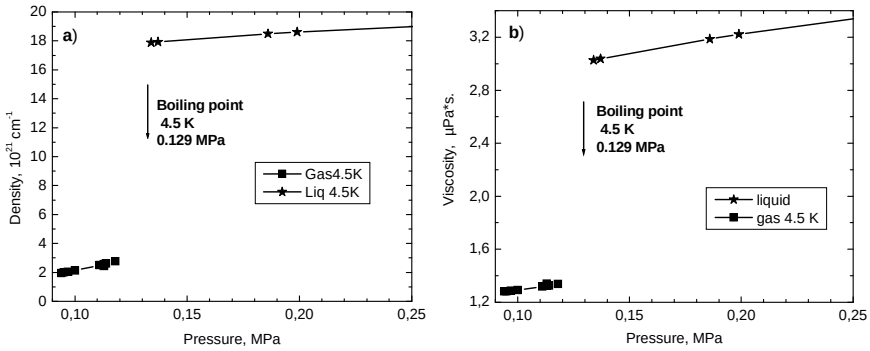

Fig. 1: Density a) and viscosity b) of Helium along the isotherm 4.5 K.

The corona discharge (ionization of matter) occurs in vicinity of a tip cathode under action of high strength electric field. Tungsten needle electrode with point radii r_p=2.5µm was used under dc high voltage. The point-plane distance was in the range of 0.65-0.8cm. The starting material was helium gas N60 (99.99990% pure, Air Liquide) which had an impurity concentration of about 0.1 ppm of oxygen. After the purification, the gas is liquefied in a cell housed in a cryostat. The temperature in the cell is measured by a germanium resistor and was fixed at 4.5 K. The stabilized dc voltage (up to 20 kV) was connected to the tungsten point electrode. The Tektronix TDS540 oscilloscope or the Keithley 610C current meter was connected to the plane electrode.

The high electric field domain located near the tip (ionization zone) was a source of charged carriers. The carriers created in the ionization zone move through a low field drift zone toward a plane electrode. The drift determined an electric current of the corona which was measured for different interelectrode voltages and different pressures. The current was in a space-charge-limited regime where a local field strength was not Laplasian one. The electric current was a quadratic function of the applied voltage V and a straight line $I^{1/2}$ vs. V had a slope proportional to carrier mobility μ [1], Figs.2. So, the mobility can be extracted from experimental data of electric current.

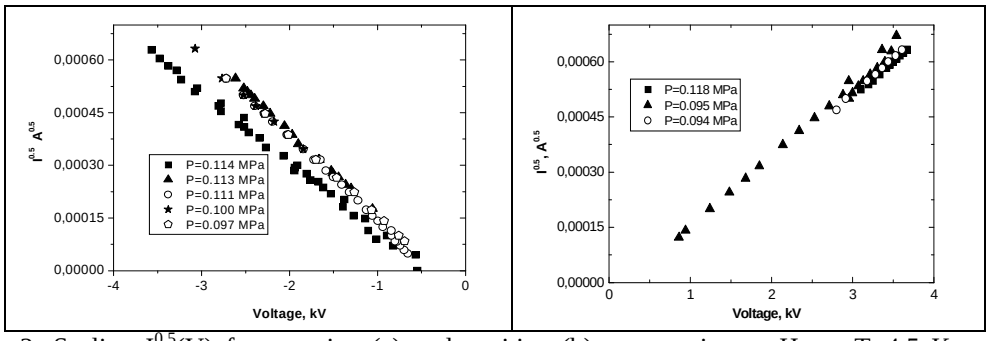

Fig. 2: Scaling $I^{0.5}(V)$ for negative (a) and positive (b) coronas ia gas He at T=4.5 K under different pressures.

The mobility of Negative carriers (empty symbols) and Positive ones (full symbols) measured in liqHe and in GasHe at 4.5K are shown in Figs.3. The arrow shows the boiling pressure 0.129MPa for this temperature. The mobility of negative carriers in GasHe is much less than a gas-kinetic mobility of electrons $1.4*10^3$ cm^2/Vs and it is comparable with mobility of positive carriers, Fig. 3 b).

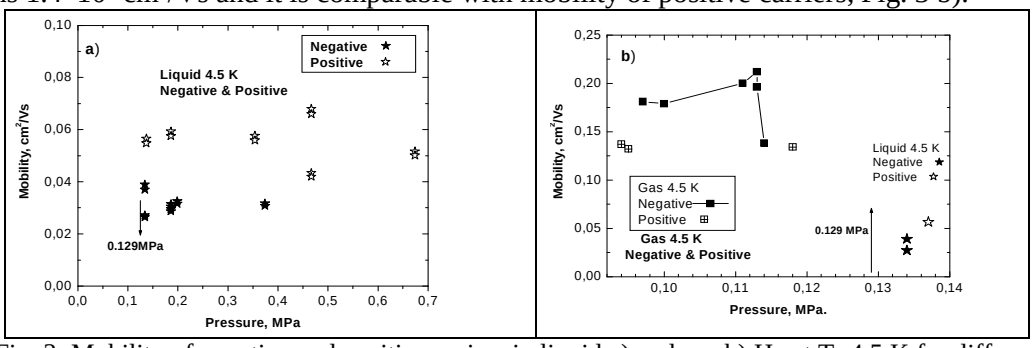

Fig. 3: Mobility of negative and positive cariers in liquid a) and gas b) He at T=4.5 K for different pressures.

The carriers move through liquid Helium as microscopic bubble (negative) [2] or snowball (positive)[3] with radius R. Their mobility is determined by the Stokes equation $\mu \propto e/(\eta R)$, η is the viscosity. So the radius is in inverse proportion of a product of mobility and viscosity. Radius of the snowball (positive) is less than radius of the bubble (negative) in liquid, Fig.4, a).

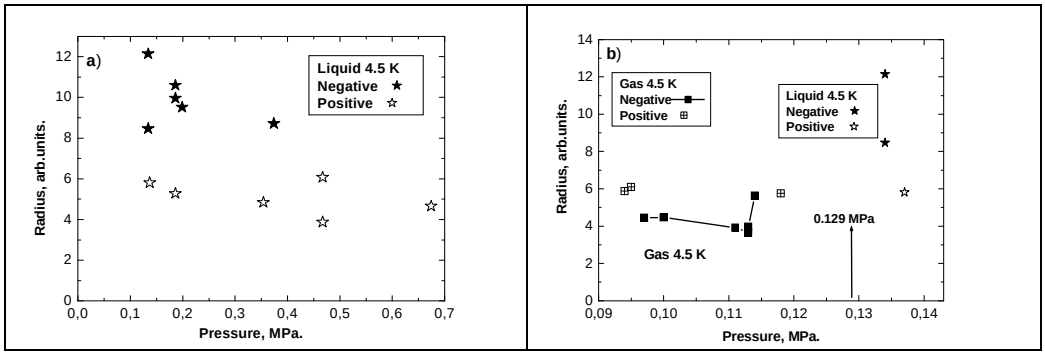

Fig. 4: Mobility of negative and positive cariers in liquid a) and gas b) He at T=4.5 K for different pressures.

This analysis made for mobility measured in GasHe gave a "radius" of carriers less than that in LiqHe. It means that the bubble/snowball model do not correspond enough with the mechanism of the carriers in the dense cryogenic gas Helium. Clusters comprised several He atoms around the charged carriers is more appropriate model for charge mobility in this condition.

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References

[1] R. Coelho, J. Debeau, *J. Phys.D: Appl. Phys*, **4** (1971) 1266.
[2] A.G. Khrapak et *al*. N.F. Schimidt and E. Illenberger (eds) (2005), chap 7, 239
[3] Atkins, *Phys. Rev.* **116** (1959) 1339