# First Observation and Mobility Measurements of Negative Ions in Superfluid $^4$He

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**Abstract**

We present the results of the first mobility measurements in superfluid helium for negative ions of different elements.Various negative ions like $F^-$, $Cl^-$ and $I^-$ were produced by laser ablation from targets consisting of NaCl, NaF, NaI, LiF and KCl immersed in a $^4$He bath. In addition to halegonide ions ablated from salts we have studied the mobility of the negative metallic ions $Ba^-$ and $Ga^-$ implanted into superfluid He.

*Key words:* superfluid helium; mobility; negative ions

## 1. Introduction

Ion mobility measurements can serve as a tool for investigating the scattering of the implanted charges with elementary excitations like phonons and rotons as well as the defect structures of the implanted ions in liquid helium. Experimental [1,2] and theoretical [3] results show a different temperature behaviour for the mobility of electrons and helium ions, so the charged particles are interacting with the excitations of the liquid helium in a different way. In this connection the question arises whether the ions of different types of atoms show a similar temperature dependence like electrons or helium ions in superfluid helium and which type of defect structure will be created. Various single positive charged ions have been investigated so far and are discussed elsewhere [4,5,6].

## 2. Experimental set-up

The mobility measurements have been carried out in a drift chamber, immersed into superfluid helium in a $^4$He bath cryostat. The helium is cooled down by evaporating the helium vapour above the surface of the helium liquid. A sketch of the drift chamber is shown in Fig. 1.

Six different probe materials are placed on a turnable feadthrough in the helium gas phase and the ions to investigate are produced by laser ablation [7]. The Nd:YAG laser is focussed onto 4.4 $\mu$m of the probe material with an energy of 4.2 mJ per pulse. The sample holder is supplied with a negative voltage to repel the negative ions from the probe material. The ions are drawn into the liquid by an electrical field of typically -90.3 V/cm and are detected at the collector. The grids at the top of the drift region avoid the influence of the potential of the sample holder into the drift field

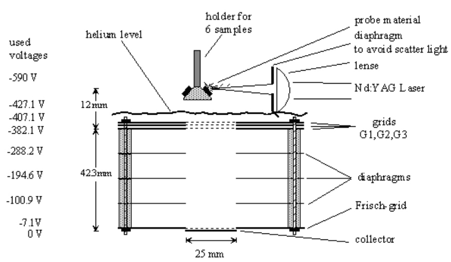


Fig. 1. Drift chamber for mobility measurements

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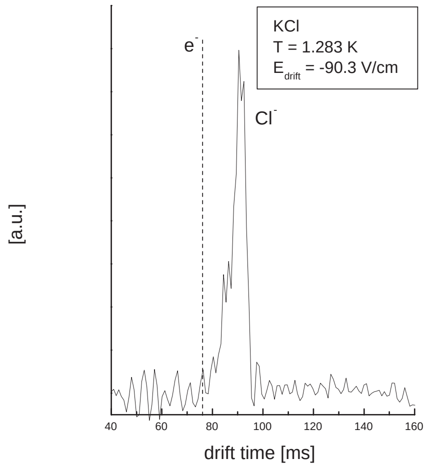


Fig. 2. Typical drift time signal of $Cl^-$ in superfluid helium at T=1.283 K and $E_{drift}$ = -90.3 V/cm in comparison to the drift time of single electrons, measured by [2]

and determine the starting point of the ions drift time. The diaphragms serve for field homogenity and the frish grid avoids induced image charges onto the collector. The ion current at the collector is amplified by an electric amplifier by a factor of $10^{10}$ V/A. The signal is converted by an voltage-to-frequency-converter and is counted into 400 channels with a time width of typically 1 ms to allow a time resolved measurement of the drift signals. The process of laser ablation and signal countig is repeated about 50 times for each run to reach a better statistic safety.

## 3. Experimental results

Different negative ions like $F^-$, $Cl^-$ and $I^-$, ablated from the salts LiF, NaF, NaCl, KCl, and NaI have been studied by mobility measurements. A typical signal of the drift time of $Cl^-$ in an electrical drift field of $E_{drift}$ = -90.3 V/cm at a temperature of T = 1.283 K can be seen in Fig.2.

In comparison to the drift time of single electrons, measured by [2], $Cl^-$ needs a longer time for the same drift length. This behaviour confirms the implantation of negative ions into superfluid helium that differ in their mobility from electrons [8] .The new results of the mobility of negative ions at a fixed temperature can be found in Table 1.

Additionally to halegonide ions ablated from salts we have studied the mobility of the negative metallic ions $Ba^-$ and $Ga^-$ that could be implanted into superfluid helium for the first time. All investigated negative ions show a lower mobility than electrons in superfluid helium. The different types of ions ablated from

Table 1
Comparison between the mobilities of different negative ions and single electrons in superfluid $^4$He at temperature 1.327 K

| Ion | Element | Average mobility [cm $^2$/(Vs)] |
|---|---|---|
| $Cl^-$ | NaCl | 0.466±0.010 |
| | KCl | 0.448±0.013 |
| $F^-$ | NaF | 0.465±0.023 |
| | LiF | 0.469±0.037 |
| $I^-$ | NaI | 0.449±0.016 |
| $Ba^-$ | Ba | 0.468±0.009 |
| $Ga^-$ | Ga | 0.408±0.011 |
| e [2] | | 0.540±0.011 |

the salts cannot be distinguished between each other in their mobility within the error bars. The mobility of $Ga^-$ is obviously the lowest one of all investigated negative ions. Additionally to single drift time measurements at a fixed temperature the temperature dependence of the ions mobility has been investigated in a temperature range from 1.283 K to 1.815 K. With decreasing temperature the difference between the inverse reduced mobility of negative ions and electrons is increasing [9].

## Acknowledgements

This work was supported in part by the Deutsche Forschungsgemeinschaft (DFG). A. K. would like to acknowledge an Alexander von Humbold postdoctoral fellowship.

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[8] In earlier mobility measurements in superfluid helium a deviation in the absolute mobility of about 10% has been found for positive helium ions by [5] in comparison to the results of [2] beyond the expected systematic and statistical errors. Due to this fact the results of [2] for the electron mobilities have been corrected in this paper to reach a reasonable comparison with our data of negative ions.

[9] A. Kasimov, C. Zühlke, K. Jungmann, G. zu Putlitz (unpublished results)