ATOMIC INTERACTION WITH QUANTUM FLUID CLUSTERS: CROSS-JET DEFLECTION OF ^{3}HE- AND ^{4}HE-CLUSTERS

by

J. Gspann and H. Vollmar

Institut für Kernverfahrenstechnik der Universität und des Kernforschungszentrums Karlsruhe, 7500 Karlsruhe, Germany

Introduction. As a consequence of the quantum properties of helium, clusters of helium atoms cannot freeze as a result of the evaporation cooling taking place during their flight through vacuum. Even at the absolute zero of temperature about 25 bars of pressure are needed for bulk liquid ^{4}He, and about 32 bars for bulk liquid ^{3}He, to solidify. These values are not reached by the internal pressures of helium clusters however small because of the small surface tensions of the helium liquids. Consequently, helium clusters are distinguished from all other kinds of clusters by remaining always liquid.

In addition, the helium liquids may become superfluid below some critical temperature which is 2.17 K for bulk liquid ^{4}He under its own vapor pressure and 0.93×10^{-3} K with unpressurized bulk liquid ^{3}He. Although the respective properties of very small free helium droplets are not known, in view of the orders of magnitude of the critical temperatures of the bulk liquid it seems rather unlikely that the evaporation cooling of clusters may suffice for ^{3}He-clusters to become superfluid while with ^{4}He-clusters it could well be the case.

We have studied earlier the velocity dependence of the total scattering of Cs atomic beams by ^{4}He-cluster beams, in comparison with corresponding experiments with N_2- and Ne-cluster beams /1, 2/. Only with the ^{4}He-cluster beams a deficiency in the effective total scattering compared to the expected behaviour has been observed which was largest near 200 m/s of relative velocity. However, it is difficult to estimate, and therefore still a matter of investigation, to which extent this effect could be attributed to the presence of a small amount of uncondensed helium atoms in the cluster beam /3/.

In the present paper we are giving a first account on an experimental study of the drag coefficients in free molecular flow of helium clusters of either isotope. The drag coefficients describe the respective efficiencies of linear momentum transfer onto the clusters and are found to be appreciably lower for helium than for nitrogen clusters /4/ which is ascribed to the fluidity of the helium clusters.

Experimental. The scheme of the experimental arrangement which is shown in figure 1 resembles closely the one used earlier for studying the mass separation of nitrogen clusters effected by cross-jet deflection /4/. The cluster beam is generated by skimming a partly condensing flow of precooled gas through a converging-diverging nozzle of 0.11 mm throat diameter and 10° initial divergence. For the generation of ^{3}He-cluster beams a nearly complete recycling of the very costly feed gas had to be installed within the experimental set-up /3/.

The cluster beam is deflected by an intersecting free jet of carbon dioxide, or of xenon, which is cryopumped by a cold trap with liquid nitrogen, or liquid neon respectively. The convergent cross-jet nozzle has an orifice diameter of 0.22 mm and may be turned around the point of intersection of the axes of the cluster beam and the cross-jet, changing the angle β in order to change the relative flow velocity. The distance of the cross-jet nozzle from the cluster beam axis is adjusted so as to produce at a suitably chosen cross-jet source pressure a deflection of the cluster beam of 2.5°, with focusing of the deflected beam /5/ at the detector entrance aperture.

The working principle of the time-of-flight mass analyser has been described in detail earlier /6/. Important changes to be noted here are the replacement of the mechanical beam chopping by pulsed electron impact ionization and the introduction of a stripper grid at the end of the cluster flight path which disassembles some of the cluster ions allowing thus sufficient post-acceleration for secondary electron multiplication to become possible.

Results. Figure 2 shows measured drag coefficients C_D of ^{3}He-, ^{4}He-, and N_2-clusters as a function of the cluster size. Since the clusters are always small compared to the mean free path in the cross-jet flow the drag coefficients pertain to free molecular flow conditions. With nitrogen clusters the earlier measured value of a drag coefficient of about 3 has been confirmed and found to be practically size-independent over 2 orders of magnitude of the cluster size.

On the other hand, the drag coefficients of helium clusters are found to be smaller than 2 and increase with increasing cluster size. The data obtained with a Xe cross-jet are somewhat below those observed with a CO_2 cross-jet but otherwise confirm the trend of the latter.

A value of the drag coefficient of 2 means that the linear momentum transferred per unit time just equals the linear momentum flow intercepted by the cross sectional area of the cluster, which has been assumed to be that of a sphere with the density of the corresponding bulk material. Drag coefficients larger than 2 normally arise from the reflection or reevaporation of the impinging particles. Drag coefficients smaller than 2 are very unusual and seem to point to a penetration of the clusters by some of the impinging particles which may be possible owing to the fluidity of the helium clusters.

Acknowledgement. The authors thank Professor E. W. Becker for his encouraging interest in this work.

References

/1/ E. W. Becker, J. Gspann, and G. Krieg, Proceed. of the 5th Intern. Symp. on Molecular Beams, Nice 1975, F. M. Devienne ed., G5

/2/ E. W. Becker, J. Gspann, and G. Krieg, Proceed. of the 14th Intern. Conf. on Low Temperature Physics, Otaniemi 1975, North-Holland Publ., Vol. 4, 426.

/3/ J. Gspann, G. Krieg, and H. Vollmar, Proceed. of the Intern. Meeting on Small Particles and Inorganic Clusters, Lyon 1976, Suppl. Journal de Physique (to be published).

/4/ J. Gspann and H. Vollmar, Rarefied Gas Dynamics, Proceed. of the 8th Intern. Symposium, Stanford 1972, Academic Press 1974, 261.

/5/ J. Gspann and H. Vollmar, Rarefied Gas Dynamics, Proceed. of the 10th Intern. Symposium, Aspen 1976 (to be published).

/6/ J. Gspann and K. Körting, Journal of Chemical Physics 59, 4726 (1973).

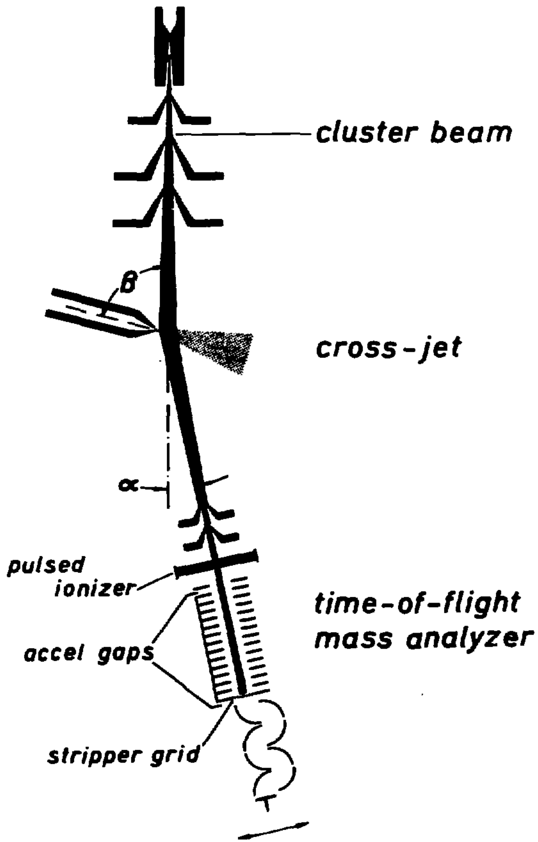

Figure 1: Schematic view of the experimental set-up.

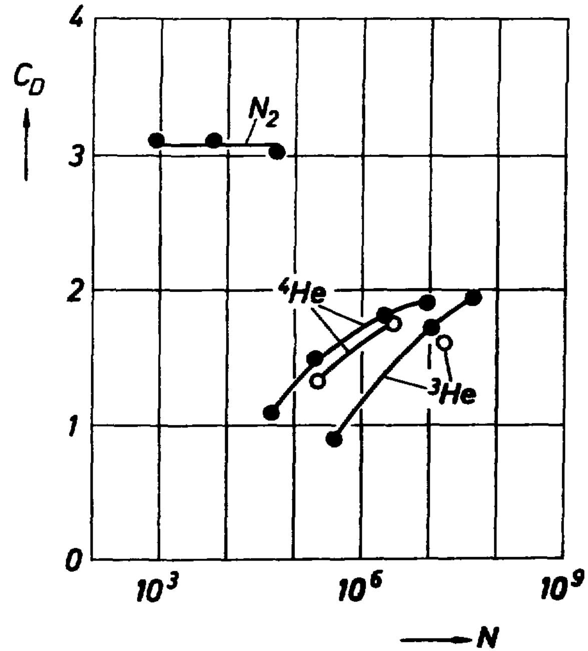

Figure 2: Drag coefficient C_D of clusters of ^3He, ^4He, or N_2 as a function of the number of atoms or molecules per cluster N. Black dots: CO_2 cross-jet; empty circles: Xe cross-jet; $\beta = 90^{\circ}$.