30 years of ultracold helium nanolabs – history and future perspectives

Wolfgang E. Ernst[1]

[1]Institute of Experimental Physics, Graz University of Technology, Graz, Austria

Abstract: More than 60 years ago, Erwin Willy Becker published a paper about beams of condensed helium[1]. Becker developed methods for uranium isoptope enrichment in Karlsruhe based on the separation nozzle process where a high-speed gas stream, comprising UF_6 highly diluted by hydrogen or helium, is forced to turn through a very small radius, separating $^{235}UF_6$ from $^{238}UF_6$ due to centrifugal forces. The observation of cold and slow beams of "condensed" hydrogen and helium were more or less a side effect.

Even earlier, one hundred years ago, the Institut für Strömungsforschung in Göttingen had been opened under the leadership of Professor Ludwig Prandtl and became a center for research on fluid dynamics. In 1969 under the roof of the Max Planck Society, one of the departments of the Institute for Fluid Dynamics was devoted to the study of molecular beams and headed for over 30 years by Jan Peter Toennies. Gas flow through tiny nozzles became a tool for surface studies and in another branch, subject of fundamental research on clusters.

Toennies and his group picked up on Becker's findings and published their detailed research on helium cluster formation at various conferences from 1985 onward[2]. During the same time, Giacinto Scoles, Professor at the University of Waterloo and later at Princeton University, used his sensitive cryogenic bolometer detection method to study IR spectra of molecules attached to inert gas clusters (first SF_6 on Ar_n) via the now widely used "pickup technique"[3].

While at first the helium clustering process and fundamental questions about finite superfluidity fascinated the small community, the application of the 0.4 Kelvin cold helium droplets as "nanolab" and as low temperature and weakly interacting confinement for atoms and molecules started to gain interest about 30 years ago. Helium droplets were doped with foreign atoms and molecules that cooled down to the droplet temperature, thus allowing for a special matrix spectroscopy. Rotational and vibrational motion of dopants inside the droplets were almost unhindered. Evidence of the anticipated finite size superfluidity in helium droplets showed up as sharp rotational lines after molecular IR excitation, as collective helium roton modes, and as vortices, all detected via measurements on dopant molecules. Due to the low temperature and almost negligible helium interaction, weak van der Waals bonds could be formed among dopants and otherwise unstable molecular conformations were observed and spectroscopically investigated. Numerous nanolab applications in a widening helium community allowed new spectroscopy in the frequency and time domains, aggregation of weakly bound clusters, creation of tailored nanoparticles, cold reaction dynamics, and more. In this talk, examples will be shown and future developments anticipated.

References:

1. Erwin W. Becker, *Z. Naturforschg.* (1961), **16a**, 1259.

2. H. Buchenau, R. Gotting, R. Minuth, A. Scheidemann, and J. P. Toennies: The Characterization of Helium Clusters in a Molecular Beam, *Lect. Notes Phys.* (1985), **235**, 157-69.

3. T.E. Gough, M. Mengel, P.A. Rowntree, and G. Scoles, *J. Chem. Phys.* (1985), **83**, 4958-4961.