The Many Fascinating Quantum Effects of Helium

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Helium is the smallest of all atoms and the only atom for which no chemistry is known. Although very rare on earth it is the second most abundant element (after hydrogen) in the universe. The very weak forces between the light bosonic ^{4}He atoms explains why it is the only substance that remains liquid down to the lowest temperatures but also why it exhibits many remarkable quantum effects.

The most spectacular is the *superfluidity* of the liquid below 2.27 K. The dramatic story behind this discovery started in 1908 when the Leiden physicist Heike Kamerlingh-Onnes won the race to liquifiy helium. Thirty years later Jack Allen and Don Miesener in Cambridge and Pyotr Kapitsa in far away Moscow not quite independently, but simultaneously, reported convincing evidence that the strange behaviour of the liquid observed since 1908 marked the transition of the liquid to a new state of matter called "superfluidity". It took another forty years before the discovery was recognized by the Nobel committee when they gave the prize to Kapitsa. Already in 1938 Fritz London speculated about the possible role of a new type of quantum "condensation" proposed by Bose and Einstein in 1924 for explaining the strange new phenomenon. Surprisingly since then and even today a completely satisfactory first principles theory of superfluidity is still not available. In 1969 Andreev and Lifshitz proposed that even the solid could become a superfluid. The first experimental evidence reported in 2004 was considered definitive until it was questioned in 2012 and today the search is still going on.

The ultra-weak bond between He atoms also leads to unexpected quantum effects in gas phase interactions which were first observed in free jet expansions in 1977. The unusually sharp velocity distributions of $< 1\%$ lead to the realization that the atom-atom cross section, at $T \rightarrow 0$ K was an extraordinary 259,000 Å^2 making it the largest cross section for scattering of ground state atoms. Subsequently the average bond distance of the dimer was measured by matter-wave-diffraction to be 52 Å making it by far the largest ground state molecule. The He trimer is an even more exotic molecule. In 1970 Efimov predicted that a zero-energy (barely) bound trimer, could have an extremely vastly extended excited quantum state which after a long search was finally confirmed in this month (May 2015) and found to have an extension of more than 300 Å!

At this meeting we are concerned with the remarkable dynamical behaviour of chromophore molecules which, when embedded in very cold (0.38 K) superfluid nanodroplets consisting of only hundreds of atoms, behave as if they were in vacuum. Similar effects have since been found in clusters with only a dozen atoms. These experiments challenge the long standing view that superfluidity is a macroscopic phenomenon and raise new challenges for a satisfactory first principles theory.

In the final section of my lecture I will briefly describe my favorite of the many exciting current helium nanodroplet experiments. I will also mention some history of the QFC meetings and analyse the development of the nanodroplet field in recent years.