Capture of heliophilic atoms by quantized vortices in ^{4}He nanodroplets

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Synopsis We present a computational study, based on time-dependent Density Functional theory, of the real time trapping of Ar and Xe atoms by superfluid ^{4}He nanodroplets either pure or hosting a quantized vortex line.

Recent experiments have shown evidence that quantized vortices in superfluid helium induce coalescence of solvated impurities, which become trapped along their cores, eventually resulting in the formation of nano-sized filaments[1], thus pointing forward to a potentially new method of producing nanowires and nanotubes[2, 3, 4]. Moreover, doping vortices with impurities has emerged as a valuable practical tool to image the vortex presence and dynamics, especially in the presence of vortex tangles and vortex reconnections.

In this work we present results obtained within TDDFT[5] for the collision and capture of Xe and Ar atoms by a $^4He_{1000}$ droplet at different kinetic energies and impact parameters. Due to the relevance of the interaction of foreign impurities with quantized vortices, special attention is paid to the time-dependent interaction of Xe and Ar atoms with helium nanodroplets hosting a vortex line.

• We study the capture of Xe atoms by a ^{4}He nanodroplet, both for head-on collisions and for different impact parameters, with velocities ranging from thermal values up to several hundreds m/s. The results of peripheral collisions with different values of the impact parameter are used to estimate the cross section for the Xe capture;

• We study how a Xe atom dynamically interacts with a droplet hosting a vortex line, under different initial conditions resulting in different velocity regimes of the impurity as it collides with the vortex core: (i) a Xe atom initially located in the interior of the droplet and close to the vortex core; (ii) a Xe atom initially at rest on the droplet surface sinking under the effect of solvation forces; (iii) a head-on collision of Xe and Ar atoms against the ^{4}He nanodroplet.

We find that Xe and Ar atoms at thermal velocities are readily captured by helium droplets, with a capture cross section similar to the geometric cross section of the droplet.

Also, upon capture, during 50 ps the Xe (or Ar) atom wanders in the bulk of the droplet at velocities of a few tens of m/s. If the droplet hosts a vortex line along the diameter of the droplet, the thermal impurity is captured by the vortex line (see also Ref. [6]).

We have found that the capture is helped by an additional energy transfer from the impurity to the droplet as compared to a capture by a non-vortical state[5]; indeed, large amplitude displacements of the vortex line take place in the course of the capture of the impurity by the vortex, constituting the main source of the kinetic energy lost by the impurity.

In short, what is of fundamental interest is that at thermal energies, most of the impurity energy is lost in the collision process. Then, if the impact parameter is such that the impurity is captured, there are two facts that contribute to the eventual meeting and capture of the Xe/Ar atom and the vortex line, namely that the vortex line is fairly robust (angular momentum conservation) and remains near the droplet symmetry axis, and that the equilibrium position of Xe/Ar is in the bulk of the droplet.

References

[1] L.F. Gomez, E. Loginov, and A.F. Vilesov, Phys. Rev. Lett. **108**, 155302 (2012).

[2] E. Latimer, D. Spence, C. Feng, A. Boatwright, A.M. Ellis, and S. Yang, Nano Lett. **14**, 2902 (2014).

[3] Ph. Thaler, A. Volk, F. Lackner, J. Steurer, D. Knez, W. Grogger, F.Hofer, and W.E. Ernst, Phys. Rev. B **90**, 155442 (2014).

[4] V. Lebedev, P. Moroshkin, B. Grobety, E.B. Gordon, A. Weis, J. Low Temp. Phys. **165**, 166 (2011).

[5] Coppens, F., Leal, A., Barranco, M. *et al*, J Low Temp Phys (2016). doi:10.1007/s10909-016-1690-x and references therein.

[6] I.A. Pshenichnyuk and N.G. Berloff, Phys. Rev. B **94**, 184505 (2016).

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