Local supersolidity of $^4$He around a charged molecular impurity

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Impurities in liquid helium are powerful probes of superfluidity and have greatly shaped our understanding of superfluid behavior [1, 2, 3]. In particular, spectroscopic studies of various molecular impurities embedded in small helium clusters have shed light on the onset of superfluidity in small quantum clusters showing that even small clusters composed of a few $^4$He atoms exhibit signs of superfluidity at the molecular scale [4, 5]. Charged impurities usually interact strongly with the surrounding helium resulting in a significant perturbation of the solvent. In the case of most cations, the helium gets strongly compressed leading to the creation of a solid core around the impurity [1, 6, 7, 8, 11, 12]. This effect, usually referred to as snowball effect [6], has been studied both theoretically [6, 7, 8] and experimentally [11, 12] in the case of atomic cations, and has been linked to a local disappearance of superfluidity within the frozen $^4$He atoms of the snowball due to their strong spatial localization [7, 8].

We will present here the results of bosonic path integral simulations [9, 10] of a charged molecular impurity, namely protonated methane, embedded in helium clusters of up to 60 $^4$He atoms at ultralow temperature. These simulations reveal that a similar snowball effect appears around molecular cations, such as CH$_5^+$, featuring a highly structured, solid-like, first helium solvation shell. Moreover, these highly localized $^4$He atoms still participate in vivid bosonic exchange that is induced by the fast ro-vibrational motion of CH$_5^+$. This combination of strong $^4$He localization with pronounced bosonic exchange, leading to an intense superfluid response, thus indicates manifestations of local supersolid behavior of $^4$He, in the first solvation shell around CH$_5^+$. We expect this impurity induced local supersolidity to appear around most positively charged molecular impurities featuring a strong interaction with the quantum solvent coupled with fast ro-vibrational motion. Hopefully, this effect can be experimentally confirmed maybe through spectroscopic studies of molecular cations in small bosonic clusters in a way similar to the ground-breaking experiments that revealed the existence of molecular scale superfluidity [4, 5].