Singular vibronic interaction in liquids: manifestation in the optical spectrum of impurity atoms in superfluid helium

V. Hizhnyakov[1], V. Boltrushko[1], G. Benedek[2,3] and P. Moroshkin[4]

[1]*Institute of Physics, University of Tartu, W. Ostwald Street 1, 50411 Tartu, Estonia*
[2]*Dipartimento di Scienza dei Materiali, Universita di Milano-Bicocca, Via R. Cozzi 53, 20125 Milano, Italy*
[3]*Donostia International Physics Center, Paseo M. de Lardizàbal 4, 20018 Donostia/San Sebastian, Spain*
[4]*School of Engineering, Brown University, Hope street 182, RI 02912, Providence, USA*

It was found that the linear vibronic interaction of impurity centers with long-wave phonons in liquids is singularly enhanced compared to this interaction in a solid. As a result, a macroscopic number of phonons with almost zero frequency is created during the electronic transition. This leads to a finite broadening of the zero phonon line (ZPL) in the optical spectrum already in the case of purely linear vibronic interaction [1]. The ultimate reason for this difference in linear vibronic interaction in a liquid is related to the fundamental difference between a solid and a liquid in transverse modes: in a solid they have a finite frequency at any wavenumber k, except k = 0, while in a liquid the frequencies are 0 at any k of these modes. This allows the liquid to isochorically change its shape in accordance with the Archimedes principle, which, in turn, leads to an exceptional amplification of the low-frequency part of the vibronic transitions in liquids. We show that taking this gain into account makes it possible to explain the strong temperature dependence of the zero-phonon transition line of the Dy atom to the inner shell in superfluid helium found in reference [2].

Our theory takes into account the presence of superfluid and normal components in superfluid helium. Due to the singular vibronic interaction, the ZPL of the superfluid component has a finite width and a symmetrical shape. The temperature dependence of the ZPL is a consequence of the temperature redistribution of the superfluid and normal components of the liquid and the temperature dependence of the ZPL of the normal component; the ZPL of the superfluid component disappears at the lambda temperature $T_\lambda = 2.17$ K. The width of the ZPL of a normal component increases linearly with increasing temperature. Our calculations of the temperature changes of the ZPL of the superfluid and normal components of the superfluid ^{4}He are in good agreement with the results of ZPL measurements [2].

[1] V. Hizhnyakov, V. Boltrushko, and G. Benedek, *Phys. Rev. B* **103**, 214515 (2021).
[2] P. Moroshkin and K. Kono, *Phys. Rev. B* **99**, 104512 (2019)