Quantum optics with ultra-narrow nuclear resonances

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Narrow optical resonances corresponding to the quantum transitions in atoms, molecules, quantum dots, rare-earth doped crystals and color centers are in the basis of quantum optics with a broad range of its applications in frequency standards, quantum sensors, quantum communication and simulation, etc. Comparable or even much higher quality factors (such as 1012 in 57Fe or 1019 in 45Sc) are intrinsically inherent to the nuclear recoilless resonances at the hard x-ray frequencies. Moreover, such high-quality nuclear resonances occur at room temperature in solids. However, the direct realization of the quantum optical concepts such as Autler-Towns splitting, EIT and optical quantum memories in the nuclear ensembles is challenging due to the absence of the relatively bright spectrally narrow hard x-ray radiation sources as well as high quality cavities. Nevertheless, several alternative techniques, developed in the second part of the 20th century (see [1-3] and the references there in), can be used for efficient acoustic/magnetic control of the quantum interfaces between the x-ray photons and nuclear ensembles. In this talk we discuss our recent demonstration of the phenomenon of the acoustically induced transparency [4,5], as well as the recent proposals for realization of quantum memory and spectral intensity enhancement [6] in the hard X-ray range. F,G. V., Y.S., and O.K. appreciate the support by the NSF, grant number PHY-2012194. Y.V. R., I.R.K., and V.A.A. acknowledge support by the Ministry of Science and Higher Education of the Russian Federation under Contract No. 14.W03.31.0032 (numerical studies). Y.V.R. acknowledges financial support of his analytical studies from the Government of the Russian Federation (Mega-Grant No. 14.W03.31.0028). I.R.Kh. acknowledges support by the Foundation for the Advancement of Theoretical Physics and Mathematics "BASIS".

[1] Yu. V. Shvyd'ko and G. V. Smirnov, J. Phys. Condens. Matter 4, 2663 (1992).

[2] Yu. V. Shvyd'ko, et al., Phys. Rev. Lett. 77, 3232 (1996).

[3] G.V. Smirnov et al., Phys. Rev. A 71, 023804 (2005).

[4] Y. V. Radeonychev et al., Phys. Rev. Lett. 124, 163602 (2020).

[5] I. R.Khairulin,et.al.,Sci Rep 11,7930 (2021).https://doi.org/10.1038/s41598-021-86555-x

[6] X. Zhang et al., Phys. Rev. Lett. 123, 250504 (2019).