Ultra-sensitive heteronuclear NMR and MRI using optical pumping

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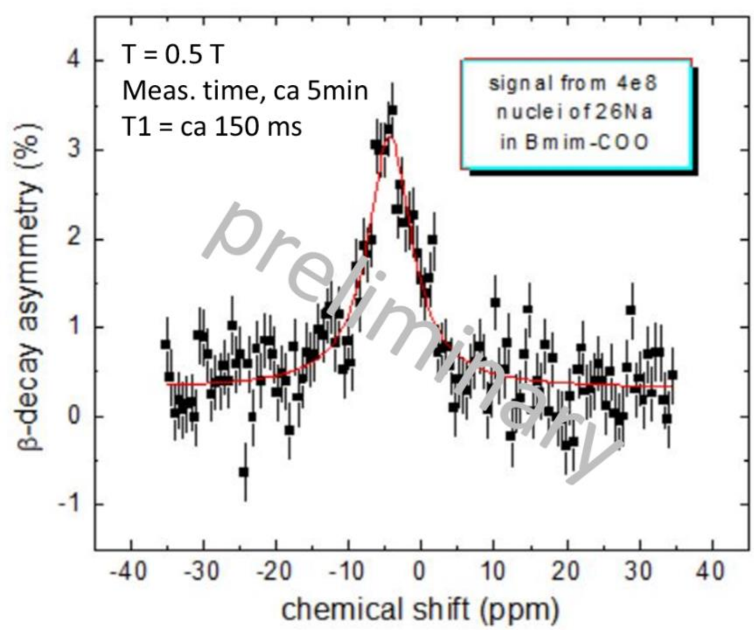
NMR is currently the most versatile and powerful spectroscopic technique for characterization of molecular structure and dynamics in solution, while MRI adds to the strengths of NMR also the spatial dimension making it an indispensable tool in medical diagnosis. However, both techniques suffer from low sensitivity, which poses constraints on the systems that may be explored. In addition, not all elements are easily accessible by NMR spectroscopy, as the most abundant isotopes display no or poor response

Our way to tackle this challenge is to increase the degree of spin polarization close to 100%, by applying optical pumping with lasers, which brings up to 5 orders of magnitude improvement in NMR/MRI sensitivity. Optionally, when this approach gets combined with observation of resonances as changes in asymmetry of radioactive beta or gamma decay [1,2] a billion-times improvement in NMR and MRI sensitivity can be achieved. This feature can in turn be used to increase sensitivity of NMR/MRI and/or decrease the pixel size in MRI.

Our experimental setup [3] is located at CERN-ISOLDE facility, where over 1000 radioactive nuclei can be produced. Optical pumping with lasers is used to polarize isotopes of different metallic elements [3]. The anisotropic emission of beta or gamma radiation from such hyperpolarized nuclei is them used to detect NMR response, leading to the above-mentioned 9 orders of magnitude higher sensitivity of the beta-NMR technique. When using stable nuclei, the signal is recorded in a conventional way, leading to 5 orders of magnitude higher sensitivity.

Laser-polarized nuclei already used for NMR studies in solid samples include isotopes of Li, Be, Na, Mg, and first studies on short-lived ^{26}Na in liquid samples were performed in 2017. Soon to be polarized are several K, Ca, Rb, Cu and Zn isotopes [1]. Our NMR studies concern the interaction of Na and K cations with DNA G-quadruplexes, present for example in telomers [4]. On the MRI side, we are working towards first MRI signals from long-lived ^{131m}Xe and later from ^{23,24}Na, which could be useful in assisting ongoing 23Na MRI activities.



[1] A. Jancso et al., J. Phys. G: Nucl. Part. Phys. 44 (2017) 064003
[2] Y. Zheng, G.W. Miller, W.A. Tobias, G.D. Cates, Nature 537, 652 (2016)
[3] M. Kowalska et al., J. Phys. G: Nucl. Part. Phys. 44 (2017) 084005
[4] M. Kowalska et al, CERN-INTC-2017-071 ; INTC-P-521 (2017)