Nuclear Resonance Scattering of Synchrotron Radiation from $^{161}$Dy at 25.6 keV

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Nuclear resonance scattering of synchrotron radiation allows to study hyperfine interactions and phonon spectra in solids. First observation was made with $^{57}$Fe in 1984 [1] at an energy of 14.4 keV. Since that time several other nuclei with transition energies up to 23 keV were studied. Nuclear resonance excitation of the 25.6 keV level in $^{101}$Dy with synchrotron radiation via a non coherent decay channel was reported in [2]. We present here first measurements of the time spectra of nuclear forward scattering (NFS) and energy spectra of the nuclear inelastic scattering with phonon excitations (NIS) performed with $^{161}$Dy nuclei.

The measurements were carried out at the 12 GeV $e^-/e^+$ storage ring PETRA. The beam was monochromized with two diamond single crystals in Laue geometry to a bandwidth of about 2 eV ((M) in Fig. 1). A backscattering monochromator (S) was used to obtain an energy band of about 8 meV [3]. Bragg backscattering allows one to reach ultimately high energy resolution with extreme large angular acceptance. In this case we used the (3 2 5 52) reflection from a sapphire single crystal at 384.4 K. A stack of avalanche photodiodes (D) was used to measure the photon flux. It allowed with the timing electronic for nuclear resonance scattering to observe nuclear decay with a time resolution of 1 ns.

In case of NFS time spectra measurements our sample was a Dy-metal foil, 25 μm thick, placed in a closed cycle cryostat with the possibility to change the temperature in a region from 20 K up to 80 K. Dy-metal is ferromagnetic at low temperatures and transforms to the antiferromagnetic state above the Curie temperature of 85 K. The Néel temperature is at 178 K. The internal magnetic field at 85 K is about 570 T which leads to a calculated component of the quantum beat spectrum with a period of 100 ps. The detector time resolution allowed us only partly to resolve the quantum beat structure of the NFS time spectrum. Figure 2 shows the measured and fitted NFS time spectra (on the left) and calculated, based on the fit results, correspondent NFS energy spectrum. We have used hyperfine parameters of the Ref. [4] as the start parameters for the fit procedure.

For the NIS measurements we detect the x-rays of the L conversion process from Dy at room temperature. In this case Dy was placed close to the avalanche photodiode.

![Figure 1: Scheme of the backscattering experiment; M: Laue premonochromator; D: x-ray detector consisting of a stack of avalanche photodiodes; F: dysprosium foil installed in a closed cycle cryostat; V: vacuum tube; S: sapphire crystal in oven; L=6m](image-url)
Figure 2: Measured time spectrum (left) from a Dy-foil at 20 K. The solid line is the result of a fit with the corresponding energy spectrum displayed on the right side.

Figure 3: Inelastic scattering of Dy$_2$O$_3$; the red curve (squares) shows the excitation spectrum in NFS the blue curve (dots) shows the spectrum in NIS.

The spectrum presented in Fig. 3 by the squares (red curve) is a time-integrated NFS spectrum in Dy-metal at 20 K measured versus the energy of the incident x-rays. The energy was changed by changing the temperature of the sapphire crystal (S). The HWFM of the curve is 8 meV. It presents the energy resolution of the used backscattering Al$_2$O$_3$(3 2 5 52) monochromator. This energy resolution has allowed us to observe nuclear inelastic scattering in Dy$_2$O$_3$ with phonon excitations - dots (blue curve) in Fig. 3. Delayed 6.7 keV L$_{α}$ fluorescence of Dy-atoms as a result of the internal conversion of the excited $^{161}$Dy nuclei was detected in this case.

References