



X-RAY INELASTIC SCATTERING WITH NUCLEAR RESONANCE TECHNIQUES

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A new technique to measure the energy distribution of X-ray inelastic scattering is developed. The well-defined transition energies in nuclei are used to analyse the energy of inelastically scattered radiation. The technique provides an easy way to study the density of vibrational states for a wide range of polymers and proteins.

The superior spectral density of radiation on the sample achieved at third generation synchrotron radiation sources allows one to establish new spectroscopies: nuclear and X-ray inelastic scattering with nuclear resonance techniques. The Nuclear Resonance beamline, ID18, [1] at the ESRF, is the first installation dedicated to nuclear resonance scattering.

The interaction of X-rays with nuclei occurs only within the very limited energy bandwidth ($\sim 0.01 \dots 0.1 \mu\text{eV}$) near the nuclear transition, and the energy of this transition stays the same under any influence. This property makes nuclear transitions an excellent energy reference. We used this reference for the energy analysis in X-ray inelastic scattering experiments with samples that do not contain resonant nuclei [2].

EXPERIMENTAL SET-UP

The experimental set-up is shown in Figure 1. The X-ray beam is prepared

by a high resolution monochromator (HRM) with 6.4 meV bandwidth. It has a compact ‘nested’ design [3], composed of Si (4 2 2) and Si (12 2 2) channel-cut crystals. The energy of the radiation is varied in steps of 1 meV in the range of ± 100 meV around the transition energy in ^{57}Fe (14413 eV). The typical flux on the sample is about 0.7×10^9 photons/s at 60 mA (16-bunch mode).

The energy of the radiation scattered by the sample is analysed using a resonance detector with a bandpass of 0.5 μeV . The detector consists of a large area (200 mm²) fast avalanche photo diode (APD) [4] covered by a 10 μm foil of α -iron, 95% enriched in the resonant ^{57}Fe isotope. The resonant performance of the detector is determined by the process of elastic nuclear scattering in the foil. If the energy of the radiation coincides with the energy of the nuclear level, it excites the ^{57}Fe nuclei and is re-emitted forward with a time delay determined by the life time of the

nuclear excited state ($\tau_0 = 141$ ns). X-rays with other energies pass through the foil instantaneously. The delayed events are separated from the prompt pulse using fast electronics. The undesirable influence of inelastic nuclear absorption in iron is avoided in the detector design. The intensity of the delayed events is measured as function of the difference between the energy of the incident beam and the energy of the nuclear level. This measurement provides the probability of inelastic scattering as a function of energy transfer.

RESULTS

Energy spectra of X-ray inelastic scattering by water, polymethyl methacrylate, and gaseous Xe are shown in Figure 2. The presence of inelastic scattering is clearly seen, both in the considerable broadening and in the long tails of the spectra. The solid lines show the fit to the experimental data using a phenomenological approach (a), the density of states obtained in neutron studies (b), and a Doppler broadening model (c) [2].

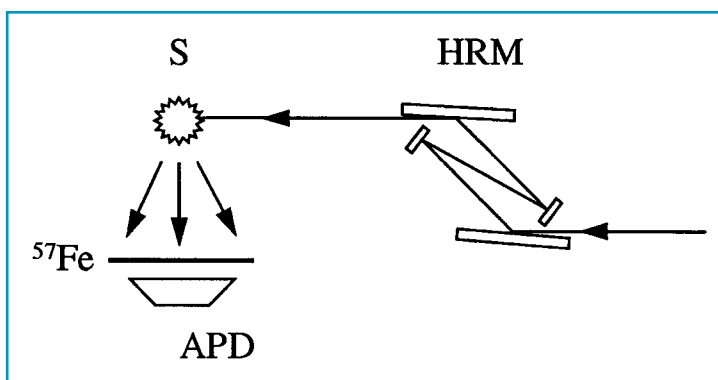


Fig. 1: Experimental set-up: HRM - compact high resolution monochromator with 6.4 meV bandpass, using Si(422) and Si(12 2 2) channel-cut crystals in a ‘nested’ geometry; S - sample; ^{57}Fe - 10 μm foil of ^{57}Fe ; APD - avalanche photo diode.



Nuclear resonant energy analysis of inelastic X-ray scattering offers a way to measure the energy distribution of the inelastic scattering, integrated over the momentum transfer. In this sense it is complementary to the conventional inelastic X-ray scattering technique with crystal optics analysis [5]. The new technique can be applied to measure a density of phonon states under the condition that q -dependence of the dynamic scattering function $S(q,\omega)$ is a common factor before the energy dependence of the scattering. This, for

instance, is the case for many types of polymers [6] and proteins [7], thus a wide field of applications is anticipated. The first application of the new technique to study the vibrational dynamics in myoglobin with 4.4 meV energy resolution (upgraded high resolution monochromator at Nuclear Resonance beamline) was performed recently [8]. ■

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Fig. 2. Energy spectra of inelastic X-ray scattering by water (a); by polymethyl methacrylate (b), and by gaseous Xe (c). Solid lines show the fit to the experimental data. As comparison, the dashed lines show the instrumental function.

