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Polarized radiation in Mössbauer spectroscopy

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Abstract

Mössbauer polarimetry is a spectroscopic technique sensitive to the orientations of hyperfine fields. The technique is particularly effective with monochromatic, polarized radiation: the measured spectra do not contain many additional transitions present when nonmonochromatic radiation is used. The paper reviews recent achievements in the construction of sources of polarized monochromatic radiation. Recently, filter techniques were adopted for achieving circularly and linearly polarized radiation from commercially available radioactive isotopes. A synchrotron source with nano-eV energy width, suitable for Mössbauer measurements was constructed. Applications are reviewed, in particular determination of the direction of the hyperfine magnetic field and the orientation of the electric field gradient. Special attention is paid to cases when the distributions of the hyperfine fields and mixed interactions result in poorly resolved spectra. Recent achievements in methodology are described. An explicit form of the intensity tensor is derived, which allows the transition probabilities to be calculated omitting the diagonalization of the Hamiltonian. The concept of the velocity moments is introduced. It is shown that some averages of the whole Mössbauer spectra relate to the averages of hyperfine fields and possess tensor properties.

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1. Introduction

The hyperfine structure of nuclear levels and the angular dependence of the nuclear transition probability bear important information about the nuclear spin interactions with its surrounding, the multipolarity of the transitions, and the strength and orientation of the hyperfine fields.

The Hamiltonian of nuclear spin exposed to a magnetic field and an electric field gradient (EFG) was analysed at the end of the 1940s [1–4]. These works were stimulated mainly by the discovery of the nuclear hyperfine fields [5,6] and the observation of the nuclear magnetic resonance in solids [7,8].

The intensity of the emitted radiation and its dependence on the orientation of the hyperfine field is determined by conservation of the angular momentum of nucleus and photon system. Hyperfine interactions remove the degeneracy of the nuclear levels. The discovery of the Mössbauer effect resulted in the development of a new tool for investigation of the nuclear transitions. Because of the unusual energetic resolution of the Mössbauer effect, separate nuclear transitions, line intensities, and polarization of the interacting photons can be observed.

During early applications of the Mössbauer technique, large effort was already being undertaken in order to construct a monochromatic, polarized source of resonant radiation [9–12]. A detailed review covering work up to 1981 was made by Gonser and Fischer in [13]. We report progress in the realization and application of the sources of monochromatic, polarized radiation. We focus on the important case of the 14.4 keV transition in ^{57}Fe [14–16]. One important field covered by Mössbauer spectroscopy concerns investigation of the properties of materials. Thus, our considerations are restricted mainly to standard Mössbauer absorbers, in which thickness effects are small. The cases of thick absorbers are reviewed in [13].

The standard Mössbauer technique deals with incoherent emission processes, and information about the phase of the scattered photons is not available. In contrast, the use of coherent nuclear scattering of synchrotron radiation offers access to the amplitudes and phases as well. Therefore, nuclear resonant scattering has become a powerful tool when new generation synchrotron sources permitted to achieve meV-resolution of X-ray monochromators. There is unquestioned