TRANSIENT HYPERFINE MAGNETIC FIELDS*

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Fast ions traversing magnetized materials experience very large transient hyperfine magnetic fields. The processes responsible for these interactions are related to the interchange of electrons between the moving ion and the polarized medium. The dependence of the transient hyperfine fields on the atomic number and the velocity of the ion, and on the magnetization of the host has been mapped for a wide range of nuclei and magnetic hosts. The experimental evidence supporting specific models will be presented and applications to the measurement of magnetic moments of short-lived excited states will be described.

1. Historical survey

It has long been well known that impurities embedded interstitially or substitutionally in magnetic materials are subject to static magnetic fields that can be either positive or negative with respect to the magnetization of the medium and that can be as large as several hundred teslas. The origin of the static hyperfine field is fairly well understood. The interactions between the nuclear moment and the static magnetic field has been used successfully in measurements of magnetic moments of nuclear states with lifetimes longer than nanoseconds, and in the determination of the electronic configurations of compounds and alloys. In 1966, the MIT—Wisconsin group [1] discovered that even larger magnetic fields act on fast ions traversing magnetized materials. These transient fields are always positive and are roughly proportional to the atomic charge of the moving ion. Borchers [1] immediately proposed a mechanism to account for the observations. He suggested that the transient fields resulted from the hyperfine interactions between the nucleus and s-electrons or vacancies in its atomic environment formed by exchange interactions with the polarized medium.

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Soon after their discovery, Lindhard and Winther [2] proposed a quantitative theoretical model (LW) to describe the transient field. They proposed a microscopic mechanism whereby the magnetic interaction arises from the Coulomb scattering of free electrons in the ferromagnetic medium by the bare charge of the moving ion. For low velocities, the electron density at the nucleus is enhanced by a factor of \( \approx 2\pi Zv_0/v \), where \( Z \) is the nuclear charge, \( v_0 = e^2/\hbar \) is the Bohr velocity, and \( v \) is the ion velocity. The theory has only a free parameter \( v_p \), the Fermi velocity of the polarized electron on the host which was adjusted to best fit the available data [3]. The LW model predicts that the transient field

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B_{\text{LW}} = \frac{8\pi}{3} \left( 1 + \frac{Z}{84} \right)^{2.5} \frac{2\pi Zv_0/v_\text{f}}{1 - e^{-2\pi Zv_0/v_\text{f}}} (1 + \xi) M
\]

is proportional to the magnetization \( M \), to the atomic number of the ion \( Z \), and to \( 1/v_\text{f} \), where \( v_\text{f} \) is the velocity of the ion relative to the scattering electron. \( \xi \) is an asymmetry parameter that accounts for the fact that at low velocities the ion is not bare.

In 1975, the Bonn-Strasbourg group [4] discovered that, contrary to expectations, the transient field increases considerably with the ion velocity; subsequent experiments in Utrecht [5] also confirmed an approximate \( Z \) dependence.

Since then, a vast array of data has been obtained for nuclei light and heavy, fast and slow, for several ferromagnets over a broad temperature range. The current estimates of the magnitude and the velocity and charge dependence of the transient hyperfine field, as well as a discussion of the present understanding of the origin of the field in terms of microscopic interactions, will be given below.

2. Experimental procedure

A variety of experimental arrangements have been used in many laboratories. Here we present the main features of a typical experimental setup [6] (fig. 1). In most experiments, the state of interest is created by either Coulomb excitation or (heavy ion, xn) reactions. The excited ion recoils through a thin ferromagnetic foil (iron or gadolinium) and stops in a thick copper or lead backing where it is not subject to any further hyperfine interactions. Gamma detectors are located at the angle \( \xi \), where the slope in the angular distribution of decay radiation is maximum (fig. 2). The magnetic material is polarized either up or down with respect to the scattering plane by a small external magnetic field, and the gamma-ray counting rate is recorded as a function of field direction. The resulting precession \( \Delta \theta \) of the angular correlation is related to the magnetic moment of the state and to the transient magnetic field by