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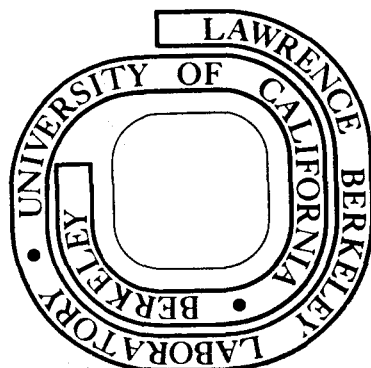
H. Bertschat, M. V. Banaschik, I. Y. Lee,
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MAGNETIC HYPERFINE FIELD OF Hg IN Ni
TIME-DIFFERENTIALLY MEASURED AFTER A HEAVY-ION REACTION*

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ABSTRACT

The magnetic hyperfine field of Hg in Ni was time-differentially measured with the observation of perturbed angular γ -ray distributions following the reaction $^{181}\text{Ta}(^{14}\text{N},5n)^{190\text{m}}\text{Hg}$. The value obtained at room temperature is $|H_{\text{hf}}| = 110(4)$ kG. No significant difference of radiation damage effects at the probe nucleus site in comparison to light-ion reaction experiments is observed, indicating that many similar time-differential measurements on magnetic hyperfine interactions might be feasible.

In recent years magnetic hyperfine fields (MHFs) in the ferromagnetic metals Fe, Co, and Ni have been measured for most of the elements of the Periodic Table,¹ many with high accuracy. However, there are a number of elements on which conventional methods, e.g., nuclear magnetic resonance, Mössbauer effect, or time-differential perturbed angular correlation (DPAC) experiments, are not applicable or lead only to uncertain results. In many of these cases the time-differential observation of perturbed angular distributions of γ -rays following a nuclear reaction (DPAD) might be the most suitable and reliable method. It has been shown that, in principle, this method is applicable within a wide temperature range yielding results with a high accuracy, both when the recoil nuclei are stopped in a ferromagnetic target itself² or, more importantly, when the product nuclei are implanted in ferromagnetic backings.³

Time-differential measurements, leading to accurate results, require the fulfillment of the condition

$$| g \mu_N H_{\text{eff}} \tau | \geq \hbar, \quad (1)$$

where μ_N is the nuclear magneton, H_{eff} is the effective magnetic field at the nuclear site and g and τ are the nuclear g -factor and the lifetime, respectively, of the isomeric state of the probe nucleus. So far, a number of cases have been studied by the application of pulsed light-ion (LI) beams; however, the use of heavy-ion (HI) reactions would cover the widest range of available isomeric states. An additional advantage of HI reactions in contrast to LI reactions (cf. Ref. 3) is the considerably

higher recoil energy of the probe nuclei. Targets can then consist simply of two layers: the target material of $\approx 1 \text{ mg cm}^{-2}$ thickness attached to a ferromagnetic foil of $\approx 1 \text{ mg cm}^{-2}$. However, at the beginning of this experiment it was not clear whether time-differential measurements of MHFs might be seriously affected by the inevitable radiation damage due to the high recoil energy, or even be totally impossible. Therefore, one main goal of this experiment was the investigation of this important question.

We have chosen to study the case of Hg in Ni. Its MHF is roughly known, i.e., reported^{1,4} values vary between -86 and -124 kG. These values were obtained by methods using radioactive sources populating isomeric states with relatively small and inaccurately known g-factors⁵ and half-lives not exceeding 7.3 nsec. Other methods, e.g., NMR, are hardly applicable due to the extremely small solubility of Hg in Ni.⁶

As an isomeric state we have picked the 10^+ state ($T_{1/2} = 20.5(10)\text{ns}$) in ^{190}Hg with the recently⁷ measured g-factor of $g = +0.383(10)$. This level was populated by the reaction $^{181}\text{Ta}(^{14}\text{N}, 5n)$ at a ^{14}N energy of 90 MeV. The pulsed beam was provided by the LBL 88-Inch Cyclotron; the natural repetition time of the beam pulses was 175 ns with an overall time resolution of 6 nsec. The target consisted of a 1.1 mg cm^{-2} layer of natural Ta evaporated onto a 2 mg cm^{-2} foil of pure (99.9%) and well annealed depolarized Ni. The γ -radiation of the excited and aligned ^{190}Hg nuclei were detected by two 8 cc planar Ge detectors positioned at 0° and 90° with respect to the beam axis. The time-dependent γ -ray intensities are given⁸ by $I = I_0 e^{-t/\tau} (1 + A_2 G_2(t) P_2(\cos\theta))$, where the perturbation factor is given⁹ as $G_2(t) = 0.2 + 0.4 \cos\omega_L t + 0.4 \cos 2\omega_L t$, when the spin precession is

observed in a target with randomly oriented domains; we neglect higher terms and corrections due to the finite size of the detectors because they contribute less than 10% of the total amplitude. The spin precession spectra were analyzed by a least-squares fit of the ratio $R(t) = (I(0^\circ) - I(90^\circ)) / (I(0^\circ) + I(90^\circ))$, thus determining the Larmor frequency ω_L which is connected to the effective magnetic field, H_{eff} , at the probe nucleus by $\hbar\omega_L = g\mu_N H_{\text{eff}}$. The effective field can be expressed¹⁰ by $H_{\text{eff}} = H_{\text{hf}} + H_{\text{ext}} - DM$, where H_{hf} is the magnetic hyperfine field, D the demagnetizing factor, and M the magnetization. In our case we had $H_{\text{ext}} = DM = 0$. Figure 1 shows the data for a spin precession spectrum and its fit. A single sharp frequency is obtained with no damping apparent within the observed time interval, indicating that this frequency is due to nuclei at substitutional lattice sites experiencing a unique magnetic field. However, the effective A_2 coefficient of $A_2 = +0.16(2)$ is considerably reduced in comparison with the estimated¹¹ value for an E2 transition of $\approx +0.35$, suggesting that about 50% of the recoiling nuclei reach substitutional sites, although this estimate is not very accurate since we did not measure the initial nuclear alignment. Most of the rest of the nuclei probably experience a broad distribution of weaker fields and some may not even reach the ferromagnetic backing. From the sharp frequency we derive a new, more accurate magnitude for the MHF of 110(4)kG, which agrees within the experimental errors with two recent measurements, 103(8) and -124(12) kG, Refs. 12 and 4, respectively. In Ref. 12 the ratios for the MHF of Hg in the host Ni, Co, Fe are very accurately determined. Our result together with the recalculated values of Ref. 12 are presented in Table 1.

When following the order of the sp elements in the sixth period of the Periodic Table from Pt through Bi,¹ the measured MHFs go through zero, changing from negative to positive fields with a very steep gradient. Theoretical predictions^{13,14} on MHFs in this region are rather uncertain. Campbell¹⁴ has developed a semiempirical model for the sp elements in ferromagnetic 3d metals mainly for the fifth period. Accurate experimental values for the respective elements in the sixth period are a critical test and might stimulate further theoretical improvement.

In the present experiment an important result is that radiation damage effects following a HI reaction, even at high energies, do not prevent time-differential measurements. (In the following discussion we disregard time-integral measurements since they give only knowledge about averaged fields.) The following arguments should be noted

(1) The reduction of the modulation amplitude by a factor of ≈ 2 is less reduction than in similar LI experiments (e.g. Ref. 3), perhaps indicating that more recoiling nuclei reach the ferromagnetic layer.

(2) A damping of the modulation amplitude, i.e., an inhomogeneous broadening of the interaction frequency, usually attributed to a time-dependent quadrupole interaction of the nuclear quadrupole moment with electric field gradients due to radiation induced lattice defects is not observed.

(3) The new value for the MHF is in substantial agreement with earlier reported values from experiments where the Hg nuclei were substitutionally implanted. The MHF for interstitial lattice sites would have quite different values.¹⁵

Thus neither the magnitude of the modulation amplitude nor its time dependence is more seriously affected than in pulsed beam experiments with lighter ions at lower energies. Even though the recoil energies vary by nearly two orders of magnitude ($\approx 0.1 - \approx 1.0$ MeV for LI reactions, 5-7 MeV in the present experiment), we have a strong indication that the radiation damage near the final site of the recoiling nucleus is rather independent of its history. This is quite plausible, since over most of the recoil path the stopping process is carried out by electrons causing defects which are healed in metals on a psec time scale, whereas near the end of the recoil path nuclear stopping becomes important, creating comparatively long-lasting lattice defects.

From these observations it can be expected that many other MHFs can be measured successfully by the DPAD method using HI reactions.

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Footnotes and References

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1. G. N. Rao, Systematics of Dilute Impurity Hyperfine Fields in Fe, Co, and Ni, to be published in Atomic Data and Nuclear Data Tables.
2. H. Bertschat, H. Haas, F. Pleiter, E. Recknagel, E. Schlodder, and B. Spellmeyer, Z. Physik 267, 299 (1974).
3. Y. K. Agarwal, H. Bertschat, H. Haas, F. Pleiter, E. Recknagel, E. Schlodder, and B. Spellmeyer, Phys. Lett. 47A, 161 (1974).
4. H.-E. Mahnke, Lawrence Berkeley Laboratory Report No. LBL-666, (1971) p. 214 (unpublished).
5. V. S. Shirley and C. M. Lederer, Table of Nuclear Moments, in Proceedings of the International Conference on Hyperfine Interactions Studied in Nuclear Reactions and Decay, Uppsala, Sweden, June 10-14, 1974.
6. F. A. Shunk, Constitution of Binary Alloys, Second Supplement (McGraw-Hill, New York, 1969), p. 431.
7. H. Bertschat, I. Y. Lee, M. V. Banaschik, F. S. Stephens, and R. M. Diamond, to be published.
8. H. Frauenfelder and R. M. Steffen, in Alpha-, Beta-, and Gamma-Ray Spectroscopy, ed. by K. Siegbahn (North-Holland, Amsterdam, 1965), Vol. 2, p. 997.

9. E. Matthias, S. S. Rosenblum, and D. A. Shirley, Phys. Rev. Lett. 14, 46 (1965).
10. For a description of this notation, see D. A. Shirley, S. S. Rosenblum, E. Matthias, Phys. Rev. 170, 363 (1968).
11. T. Yamazaki, Nucl. Data A3, 1 (1967).
12. K. Krien, A. G. Bibiloni, K. Freitag, J. C. Soares, and R. Vianden, Phys. Rev. B8, 2248 (1973).
13. A. E. Balabanov and N. N. Delyagin, Soviet Phys. JETP 27, 752 (1968).
14. I. A. Campbell, J. Phys. C2, 1338 (1969).
15. R. P. Livi, F. P. Livi, J. D. Rogers, and F. C. Zawislak, Phys. Rev. B8, 3098 (1973).

FIGURE CAPTION

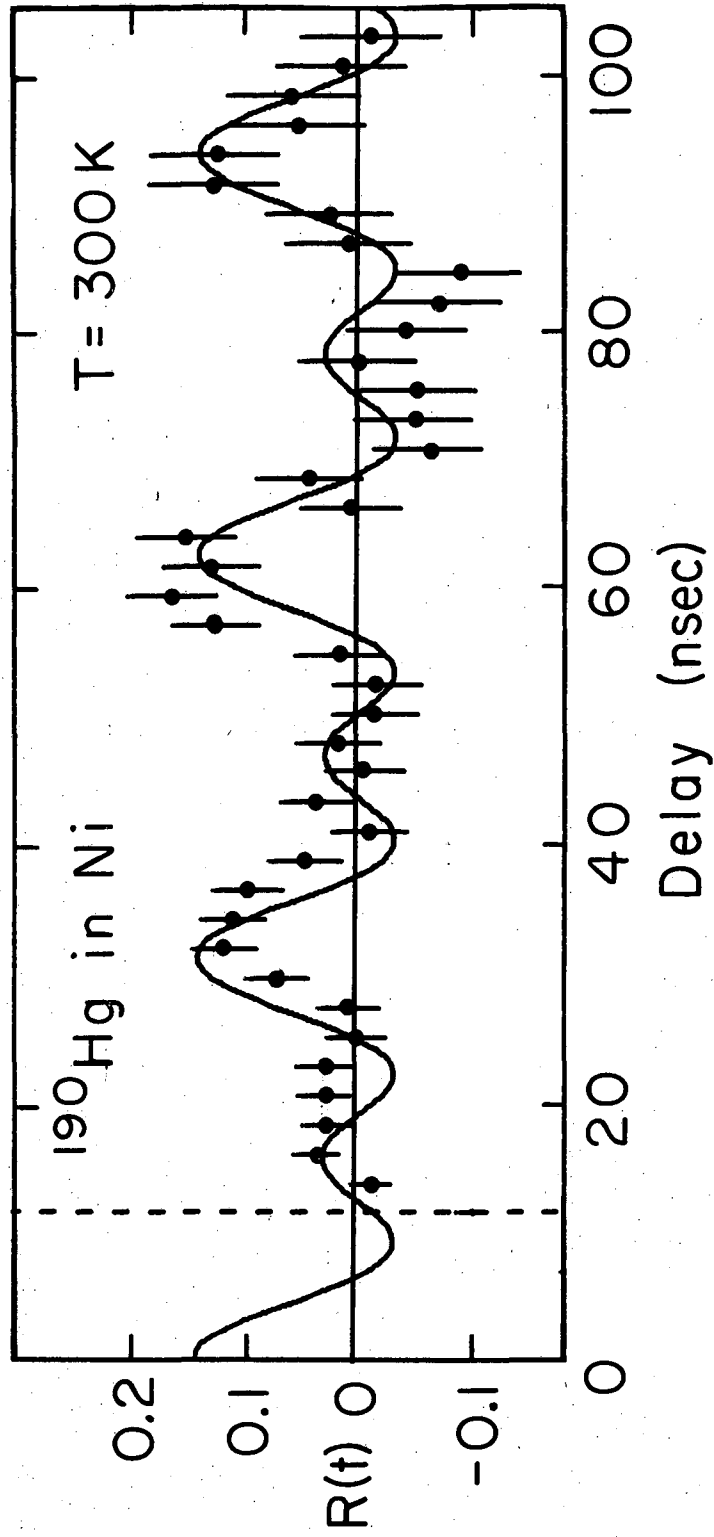
Figure 1. Time-differential spin precession spectrum of ^{190}Hg nuclei in nickel at room temperature with randomly oriented domains.

TABLE 1. *Magnetic hyperfine fields for Hg at room temperature.*

Host	H_{hf} (kG)
Ni	-110(4) ^a
Co	-520(30) ^b
Fe	-765(40) ^b

^aThe sign is known from earlier measurements.

^bRecalculated from Ref. 12 using the Larmor frequencies measured in unmagnetized foils.



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Fig.1

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