conducting state comes from the absence of "light" electrons in the de Haas–van Alphen[11] and cyclotron resonance[12] measurements on normal tin. At low temperatures (e.g., $t<0.7$) one band of "light" electrons is excited ($\alpha_0=2.17$), while near T_c a second band appears ($\alpha_0=5$). As soon as the second band of "lighter" electrons is excited, their effect completely dominates $\Delta X_L(H_0)$. The apparent temperature independence of α_0 is compatible with an exponential E vs k for the "light" bands of normal electrons.

It is hoped that a more detailed experimental study will be able to decide upon the electronic band structure of the superconducting state.

The authors wish to acknowledge the hospitality of the Institute for the Study of Metals, University of Chicago, where the measurements were made.

*Supported in part by the Office of Naval Research.
†National Science Foundation postdoctoral fellow.

[1]A. B. Pippard, Trans. Roy. Soc. (London) A250, 325 (1957).
[2]B. Lax, Revs. Modern Phys. 30, 122 (1958).
[3]M. Spiewak, Phys. Rev. 113, 1479 (1959). Data refer to sample Sn3 of this paper..
[4]G. Dresselhaus and M. S. Dresselhaus, Phys. Rev. (to be published).
[5]R. G. Chambers, Proc. Roy. Soc. (London) A215, 481 (1952).
[6]B. Serin, Handbuch der Physik (Springer-Verlag, Berlin, 1956), Vol. XV, Chap. IV, p. 244.
[7]D. C. Mattis and G. Dresselhaus, Phys. Rev. 111, 403 (1958).
[8]R. Kaplan, A. H. Nethercot, and H. A. Boorse, Phys. Rev. 116, 270 (1959).
[9]M. D. Sturge, Proc. Roy. Soc. (London) A246, 570 (1958).
[10]P. B. Miller (to be published).
[11]D. Shoenberg, Physica 19, 791 (1953).
[12]E. Fawcett, Phys. Rev. 103, 1582 (1956); A. F. Kip, D. N. Langenberg, B. Rosenblum, and G. Wagoner, Phys. Rev. 108, 494 (1957).

MEASUREMENT OF LOCAL FIELDS AT IMPURITY Fe^{57} ATOMS USING THE MÖSSBAUER EFFECT

G. K. Wertheim
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received March 21, 1960; revised manuscript received March 25, 1960)

The Mössbauer effect[1] of Fe^{57}[2] has proved to be a convenient tool for the investigation of local magnetic fields in the transition metals, where other methods have not been entirely successful. We have investigated the local fields in Fe, Co, and Ni, as well as in a number of other substances.

The sources we used were prepared in a number of different ways. A source of Co^{57} in metallic iron was prepared by electroplating from a carrier-free $CoCl_2$ solution onto a high-purity iron foil 0.0025 cm in thickness, and then diffusing at 950°C in a hydrogen atmosphere. Sources in metallic cobalt and nickel were prepared by evaporating some of the $CoCl_2$ solution to dryness on a foil of the metal and diffusing as before. Each source was then mounted on a loudspeaker voice coil driven at constant velocity with a symmetrical sawtooth wave of such magnitude as to produce a 1-mm excursion of the coil. No distinction was made between positive and negative velocity, and counting was continued through turn-around.

As an absorber we have most commonly used a 0.0025-cm foil of Type 310 stainless steel (25% chromium, 20% nickel). This material, although paramagnetic, exhibits an unsplit absorption line, indicating that the spin correlation time τ is sufficiently short to satisfy the relationship $\tau A/\hbar \ll 1$, where A is the hyperfine coupling of the Fe^{57} nucleus. We have also used diamagnetic potassium ferrocyanide which, as expected, also exhibits an unsplit absorption line. The salt $K_4Fe(CN)_6\cdot 3H_2O$ was crushed, mixed with a small amount of binder, and formed into a uniform sheet 0.08 cm thick. This thickness was chosen to make the sheet contain the same amount of Fe^{57} per unit area as a metallic iron foil 0.0025 cm thick. However, the high density of foreign matter makes this absorber less attractive than the stainless steel.

Results obtained with the iron source at room temperature and the potassium ferrocyanide absorber at 78°K, Fig. 1(a), directly exhibit the hyperfine structure of Fe^{57}. The three absorption lines yield values for the nuclear g factor for the

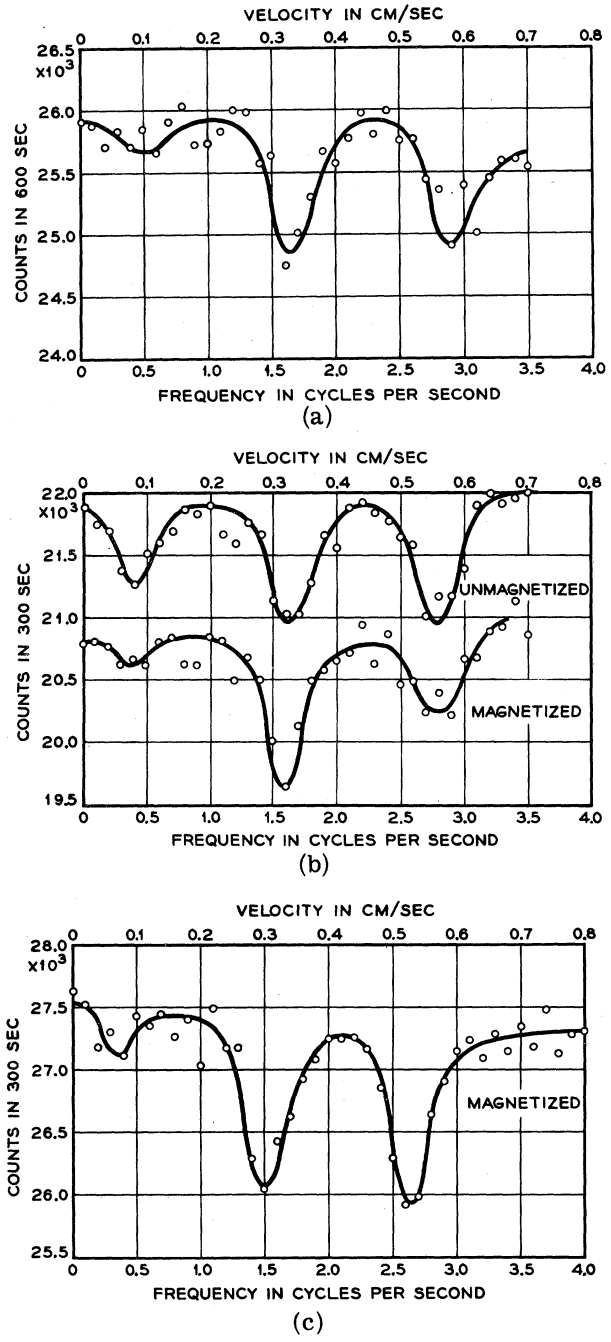

FIG. 1. (a) The hyperfine structure of Fe^{57} in metallic iron obtained with a potassium ferrocyanide absorber. (b) The hyperfine structure of Fe^{57} in metallic iron obtained with a stainless steel absorber. (c) The hyperfine structure of Fe^{57} in metallic cobalt obtained with a stainless steel absorber.

first excited state and for the magnetic field at the nucleus which are in good agreement with the earlier determination by the Argonne group.[3] The observed effect is reduced by 35% if the absorber is at 300°K. Similar results obtained with the stainless steel absorber, for the cases of magnetized and unmagnetized iron foil source, are shown in Fig. 1(b). The relative intensity of the three lines indicates that there is some remanent magnetization in the source which strengthens the middle hyperfine line even in the absence of an external magnetic field. Figure 1(c) shows the results obtained when the iron foil source is replaced by a cobalt metal foil. The small shift in the location of the hyperfine lines indicates that the magnetic field at the Fe^{57} nucleus in cobalt metal is 3.1×10^5 oe, which may be compared to the value of 3.3×10^5 oe in iron metal. In nickel, at room temperature where the magnetization is 0.95 of the saturation value, the corresponding field is 2.6×10^5 oe. A more detailed investigation of this question is in progress.

The linewidths in the stainless steel experiment are significantly larger than those obtained in the original Fe^{57} experiment,[2] in which both source and absorber were iron metal. The earlier experiment has been duplicated with our equipment, yielding results in agreement with those in the literature. Line broadening could arise in the stainless steel experiments from a spin correlation time which is insufficiently short. If this were the dominant effect it should be possible to obtain a measure of the spin correlation time in the stainless steel through the relation $\Delta\nu>2\tau I^2A^2/\hbar^2$. The observed line width, $\Delta\nu$, corresponds to a correlation time $\tau\leq10^{-10}$ sec. On the other hand, the line broadening might also arise from the combining of positive and negative velocities in the experimental setup, provided there is a shift in the energy of the emitted gamma ray relative to resonant energy of the absorber. Such shifts may be due to the second order Doppler effects[4] or due to differences in the environment of the iron nuclei in the source and in the absorber. We have observed a shift of this nature for Fe^{57} in Ge.

In addition to our experiments with transition metals, we have also observed the Mössbauer effect of Fe^{57} in n-type silicon. The source was prepared in a manner similar to that described for the cobalt and nickel foils above; as a final step, it was etched in hydrofluoric acid to remove any oxide layer which might contain Co^{57} in a different environment. Consistent results were obtained with both the stainless steel and the potassium ferrocyanide absorbers. The data in Fig. 2 show that the hyperfine field at an iron nucleus occupying a site characteristic of a cobalt atom in silicon is approximately 3×10^4 oe. This value is very much smaller than that found

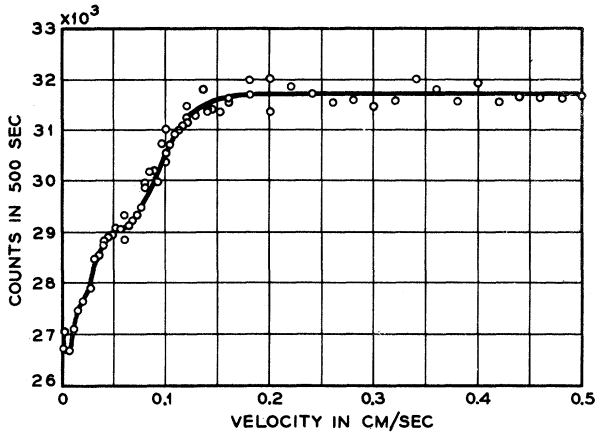

FIG. 2. The hyperfine structure of Fe^{57} in n-type silicon obtained with a stainless steel absorber.

for iron in a normal iron site.[5] The silicon source exhibits sufficiently weak hyperfine coupling so that samples of this type may be useful as unsplit sources in the investigation of other iron-bearing materials. They have the advantage over sources made by incorporating Co^{57} into stainless steel or potassium ferrocyanide that self-absorption in the source is negligible due to the absence of stable Fe^{57}.

The author is indebted to W. L. Brown, V. Jaccarino, and W. E. Blumberg for discussions and suggestions during the course of this work; to K. M. Olsen for the high-purity iron, nickel, and stainless steel foils used in these investigations; and to H. C. Montgomery, G. Feher, and J. Eisinger for the loan of numerous pieces of equipment.

[1]R. L. Mössbauer, Z. Physik 151, 124 (1958); Naturwissenschaften 45, 538 (1958); Z. Naturforsch. 14a, 211 (1959).
[2]R. V. Pound and G. A. Rebka, Jr., Phys. Rev. Letters 3, 554 (1959).
[3]S. S. Hanna et al., Phys. Rev. Letters 4, 177 (1960).
[4]R. V. Pound and G. A. Rebka, Jr., Phys. Rev. Letters 4, 274 (1960).
[5]H. H. Woodbury and G. W. Ludwig, Phys. Rev. 117, 102 (1960).

RECOILLESS RAYLEIGH SCATTERING IN SOLIDS

C. Tzara and R. Barloutaud
Centre d'Études Nucléaires de Saclay, Gif-sur-Yvette (Seine-et-Oise), France
(Received March 21, 1960)

Using the Mössbauer effect, photon sources and analyzers extremely selective in energy are now available. We study here with such an analyzer the recoilless Rayleigh scattering by atoms in solids.

This effect is related to the x-ray diffraction by crystals as follows. The interference at the exact Bragg angles occurs when the scattering is elastic with respect to the lattice as a whole, that is, without any phonon exchange. Debye and Waller have calculated the reduction in intensity of x rays scattered at the Bragg angles in a solid at temperature T,[1]

$$\varphi_T = \exp\left\{-\frac{3}{2}\frac{E_R}{k\theta}\left[\frac{1}{4}+\frac{1}{x}\int_0^x \frac{u\,du}{e^u-1}\right]\right\}, \qquad (1)$$

where $x = T/\theta$, θ is the Debye temperature, and $E_R = (E^2/Mc^2)(1-\cos\theta)$ is the recoil energy given to the free atom by a photon of energy E scattered at the angle θ.

In the present work, where we detect the elastic scattering directly by an energy selection instead of analyzing a diffraction pattern, the factor φ_T is the relative number of photons scattered without energy change. It is clearly the same factor which gives the proportion of recoilless γ rays in the Mössbauer effect[2]; in that case $E_R = E^2/2Mc^2$ in Eq. (1).

In order to measure the factor φ_T, we have studied the Rayleigh scattering for several materials: Pt, Al, graphite, and paraffin. The 23.8-kev photons emitted by Sn^{119*} were scattered at $50° \pm 5°$ and absorbed by a Sn^{119} foil 40 mg cm^{-2} thick (almost completely black for the recoilless photons[3]) (Fig. 1). The scatterers' thicknesses were such that the transmission of the γ rays was of the order of 10%.

The Rayleigh-scattered photons are accompanied by inelastically scattered photons (Raman, Compton), considerably shifted in energy, so that the selective absorption in Sn^{119} occurs only