these results as a possible explanation of the fine structure observed by Tinkham and co-workers[4,5] in their infrared absorption measurements in some superconductors. They may also partly account for the rules according to which maximal transition temperatures for s - d superconductors are observed at conduction electron concentrations corresponding to at least some of the maxima in the N_d curve. Even though the d electrons may not participate directly in the phenomenon of superconductivity ($V_d = 0$), the s electrons can benefit from the higher density of states in the d band.

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RESONANT ABSORPTION OF THE 14.4-kev γ RAY FROM 0.10-μsec Fe^{57}†

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We wish to report experiments on the resonant scattering of a recoil-free γ ray[1] which appears to be sharp enough to be used for an experimental determination of the "gravitational red-shift," as proposed in our recent note.[2]

Our initial work has been with the 14.4-kev γ ray of 0.10-microsecond Fe^{57}. Although we first worked with a source of the 270-day parent Co^{57} extracted from an iron foil kindly irradiated for us with the deuteron beam at the MIT cyclotron, an intense background of Co^{56} rendered that source poor for our purposes. Most of our work has been with Co^{57} obtained commercially.

About 50 microcuries of Co^{57} was electroplated together with added iron onto one face of a one-centimeter square of thin Armco iron.

Initial studies of the absorption of a 0.001-in. thick iron foil at temperatures of liquid nitrogen and at room temperature indicated that the desired resonant absorption was present, that the ratio of about 3:2 of the magnitudes at the two temperatures was in reasonable agreement with theory, but that the absorption was small and the line was broad compared to its natural breadth. In these experiments crude 60-cycle magnetic vibrators were used to destroy resonance and to observe the line widths. The increase in intensity available by the use of low temperatures is so small that we henceforth operated at room temperature, in the interest of stability.

The supposition that the hyperfine structure splittings of the ferromagnetic source and absorber were not fully equivalent led us to try heat treatments of the source and absorber foils. A dramatic improvement resulted after the source had been held at 950°C for an hour, which treatment was expected to result in diffusion of the cobalt, if it were retained on the surface initially, into the lattice a mean distance of about 3×10^{-5} cm, or 1000 lattice spaces. We have discovered that there was probably about 0.1 mg of stable cobalt carrier present in our source which may be important in making such treatment necessary. With the absorber foil first used, which was found to contain 3% silicon, replaced by one rolled from Armco iron to 11.5 mg/cm^2 thickness, and annealed, the line shown in Fig. 1 was obtained.

These data represent counts above background of the 14.4-kev γ ray as made with a scintillation spectrometer, using a 0.040-in. by $\frac{3}{4}$-in. NaI(Tl) crystal[3] and a single-channel pulse-height analyzer set to accept most of the full-energy peak.

All but about fifteen percent of the counts in the channel arose from the γ ray, from evidence obtained with absorbing foils. Each point is based on about 2.3×10^5 counts shared equally between conditions with the source fixed and with it moving toward and away from the absorber at constant speed. The motion was produced by a moving-coil magnetic transducer on which the source was cemented and which was supplied with a ten-cycle-per-second triangular waveform of current of adjustable amplitude.

The resonant absorption is halved by a Doppler speed of $|v_{1/2}| = 0.017$ cm/sec (which, incidentally,

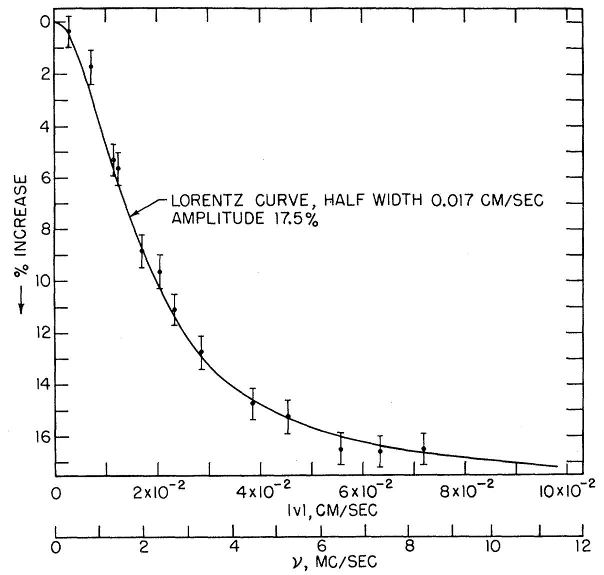

FIG. 1. The percentage increase in intensity of the 14.4-kev γ ray as a function of the absolute value of the velocity of the source. A velocity of 0.01 cm/sec corresponds to a frequency displacement of 1.16 Mc/sec.

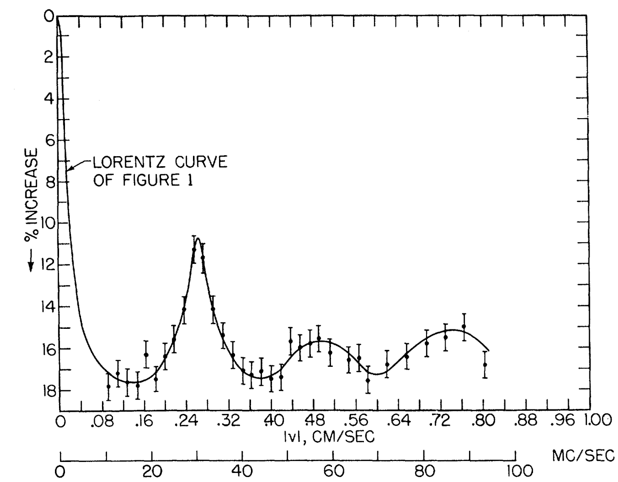

FIG. 2. The increase in intensity for velocities large enough to show hyperfine structure. There appear to be three principal satellites which probably correspond to the hyperfine structure interaction of the 0.10-μsec metastable, spin 3/2, nucleus with the internal effective magnetic field.

corresponds to only 0.0009 cm peak-peak amplitude at 10 cps). This is to be compared to 0.0095 cm/sec to be expected from energy and lifetime considerations for a "thin" absorber if no broadening exists other than from the lifetime. We are not certain that our initial difficulties with effects from the surface or the cobalt carrier are entirely eliminated and we are inclined to attribute the residual broadening by a factor of approximately two at least partly to such causes.

Our experimental width at half-height is approximately 10^{-12} times the velocity of light and represents a 100-fold reduction compared to the example reported by Mössbauer[1] and others.[4,5]

It is known that hyperfine splitting exists in ferromagnetic metals. The 14.4-kev γ ray is thought to be a magnetic dipolar transition and, with an excited state spin of 3/2 and ground-state spin of 1/2, the radiation ought to consist of six hyperfine components and the absorber should have a matched set of six lines. With appropriate Doppler speeds at the source, displacements should be found that produce partial overlaps of the lines, yielding a form of hyperfine satellites. In a limited study, we have found some structure we believe to be of this type. The results are shown in Fig. 2. We do not wish to take the space here to give the straightforward theoretical description of the hyperfine structure which we will do in a more complete report later.

There appear to be three satellite lines, the innermost occurring at a speed $|v| = 0.26$ cm/sec, corresponding to a frequency shift of 30.5 Mc/sec. The g factor of the ground state of Fe^{57} is known to be small,[6,7] although 20 Mc/sec of splitting has been observed in stable Fe^{57} as an impurity in silicon.[8] If the ground-state splitting is negligible—or contributes only to the line widths observed—the three satellite lines of integrated intensities 3/4, 1/2, and 1/4 times that of the center line would fall at Doppler frequencies equal to one, two, and three times the Larmor frequency of the spin 3/2 excited state in the effective classical magnetic field at the nucleus in the ferromagnet. According to this interpretation the Larmor frequency of the excited state is about 30 Mc/sec and its magnetic moment is large compared to that of the ground state. The breadth of the satellites may be caused in part by inconstancy of the speed of the transducer during a modulation cycle. We are engaged in improving this as well as in processing a source of much larger activity in the interest of gathering more detailed data. Until we know the details of the hyperfine structure more fully, we cannot make an exact comparison of the magnitude of the scattering with theory because the cross sections depend upon the degree of resolution of the lines.

We are now confident that we can perform the gravitational experiment inside the laboratory using this γ ray from Fe^{57}. With the line width we have found, a measurable shift of the line center is predicted by the principle of equivalence[9] for the height difference available to us inside this laboratory.

With a source of limited strength, statistical fluctuations decrease the definition of the line, owing to decreased counting rates, in a way that just compensates, assuming the inverse square law to apply over the path, the linear increase in shift as the height difference between source and absorber is increased. Use of very large vertical distances do not appear to offer much increase in precision.

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RECOILLESS RESONANCE ABSORPTION OF GAMMA RAYS IN Fe^{57}

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The recent observation that at low temperatures gamma-ray absorption and emission could take place without recoil,[1,2] has led to the suggestion that it might be of use in measuring hyperfine splittings of gamma-ray lines caused by effective magnetic fields acting on the magnetic moment of the nucleus.[2] This technique would be of particular interest in ferromagnets and antiferromagnets where other methods of measuring these fields are severely limited.

A particularly favorable case for recoilless emission or absorption is in the decay of the 14-kev first excited state of Fe^{57}. Here the Debye-Waller factor predicts that at room temperature 63 % of the gamma rays should be emitted without recoil. A source of Co^{57} has been prepared by bombarding a 0.0005-in. Fe foil by 4-Mev deuterons from the Harwell Van de Graaff accelerator. An absorber of a similar Fe foil (containing 2.2 % Fe^{57}) was used with a xenon-filled proportional counter to detect the 14-kev radiation. The source was mounted on the diaphragm of a loud speaker. The number of gamma rays emerging from the absorber with the source moving with a velocity large compared to the width of the line was approximately 20 % larger than the number of gamma rays with the source stationary. This can be compared with the 1-2 % absorption which has been reported at low temperatures previously.[1,2] This is approximately in agreement with the effect expected from the above Debye-Waller factor assuming the line to be split by the hyperfine interaction (if the latter were zero the effect would have been several times larger). The effect could be increased by using enriched Fe. Cooling the source to liquid air temperatures would increase the effect only by about 40 %.

Since the magnetic field in Fe is expected to be approximately 200 kilogauss, one would expect the hyperfine splitting to be several times the line width of 4.5×10^{-9} ev even for the ground-state magnetic moment of 0.05 nuclear magneton. The excited state presumably will have a larger magnetic moment and thus give rise to even larger splittings. It should be very easy to introduce Fe^{57} into various alloys and compounds and obtain relative values of the hyperfine fields. These could also be measured easily as a function of temperature. Apparatus for such experiments is under construction.

It has been suggested by T. E. Cranshaw that the size of the absorption and the narrowness of the line makes this an ideal case for measuring