

Local Magnetic Fields in Fe-Al Alloys

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In apparent contrast with recent results in Fe-Co and Fe-Ni alloys, the Mössbauer spectra in ferromagnetic Fe-Al alloys are both blurred and contracted as the fraction of aluminum atoms is increased. This phenomenon is consistent with a model where the inner field at a given iron atom depends strongly on the number of aluminum nearest neighbors.

INTRODUCTION

AS part of an investigation of the internal magnetic field in iron near the Curie point, the absorption spectrum of a foil of 52% Fe, 40% Ni, and 8% Cr was taken with a Mössbauer analyzer. Even at temperatures far below the Curie point only a broad blur was found, in marked contrast to the "six-finger" pattern observed in soft iron foils.

The most reasonable explanation for this phenomenon seemed to be that the effective magnetic field at an iron nucleus depends on its *local* environment, which varies from atom to atom as a result of the statistical fluctuations in composition in a solid solution. A ternary system is clearly unsuited to an investigation of this sort. Therefore we chose the iron-aluminum binary system in which there is an extensive range of solid solubility and some useful neutron diffraction data.

EXPERIMENTAL PROCEDURE

Alloys of iron with 6 and 12 atomic % aluminum were prepared from high purity iron and aluminum by levi-

tation melting, and reduced to approximately 1.5-mil foil by cold rolling. High purity alloy foils containing 17 and 28% aluminum were available from previous magnetic investigations. Measurements of x-ray diffuse scattering showed that no appreciable local order was present in the alloys as rolled, in a severely cold worked state. The Mössbauer spectra were measured for pure iron and the alloys using a stainless steel source, moved sinusoidally, and a velocity sorting system as described previously.¹

EXPERIMENTAL RESULTS

The experimental points are plotted in Figs. 1-5. The error flags are computed merely from counting statistics and are taken such that 63% of the events are included within the flag. The pattern for pure iron is in good agreement with measurements elsewhere.² The amplitude of its six peaks are in approximately the correct ratios

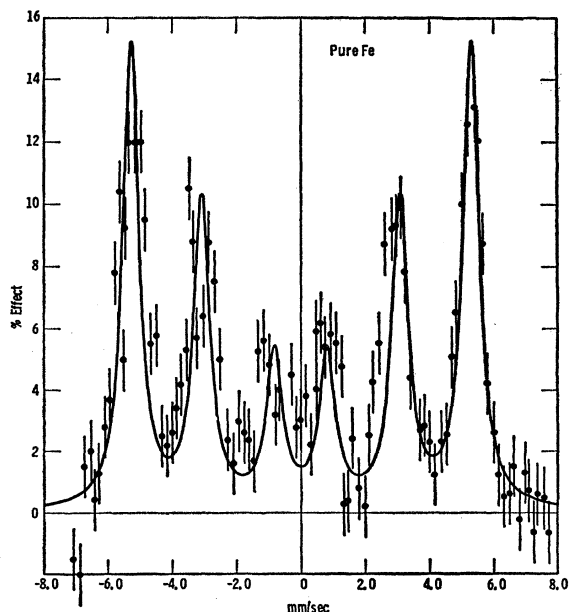


FIG. 1. Mössbauer spectra of pure iron.

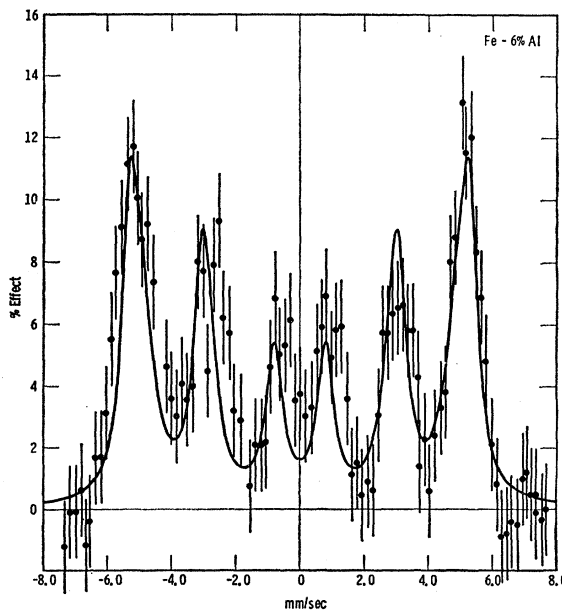


FIG. 2. Mössbauer spectra of iron-6 atomic percent aluminum alloy.

¹ S. L. Ruby and D. I. Bolef, *Phys. Rev. Letters* **5**, 5 (1960).

² D. E. Nagle *et al.*, *Phys. Rev. Letters* **5**, 364 (1960).

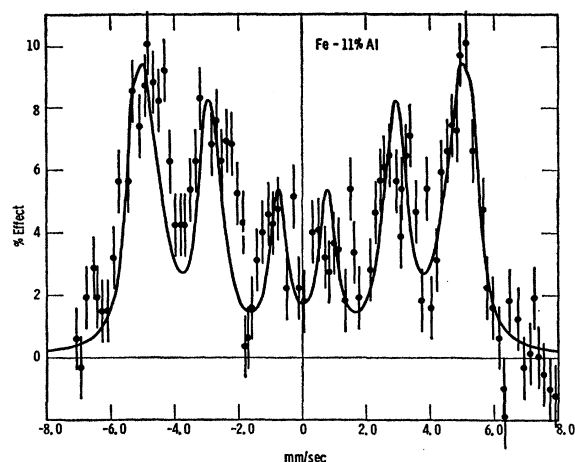


FIG. 3. Mössbauer spectra of iron-11 atomic percent aluminum alloy.

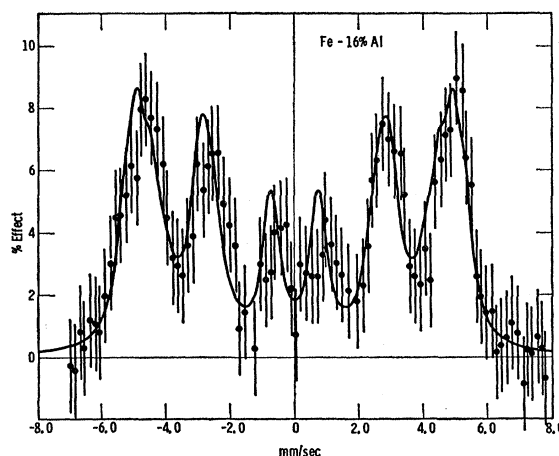


FIG. 4. Mössbauer spectra of iron-16 atomic percent aluminum alloy.

3:2:1. The full width at half maximum is about 0.55 mm/sec, a conventional figure for a stainless steel source. In the alloys we also observe six line patterns but the lines increase in breadth and decrease in amplitude with increasing aluminum content. Also the outermost peaks show the most broadening. The derivation of the solid lines in the figures will be discussed below, but it should be noticed that each spectrum has been separately normalized to the appropriate calculated curves.

INTERPRETATION OF RESULTS

Measurements of the Mössbauer effect in pure iron as a function of temperature indicate that the internal field is accurately proportional to the average moment per atom.² We assume that the same is true for individual iron atoms in our alloys. Neutron diffraction measurements on fully ordered Fe₃Al have shown that iron atoms in sites surrounded entirely by iron have approximately the same moments as in pure iron, while those with four aluminum and four iron neighbors have moments only 0.68 as great.³ Since fully ordered FeAl is nonmagnetic, the iron atoms with all aluminum nearest neighbors have no net moment.

We now assume that the moment per iron atom varies smoothly with the number of aluminum neighbors in such a way as to pass through these three points. For purposes of interpolation we chose the functional relation

$$H = H_0(1 - n/8)^k, \quad (1)$$

where n = number of aluminum neighbors; H_0 = 330 kgauss, the value of the internal field for pure iron at room temperature; k = 0.556 to fit the Fe₃Al neutron diffraction datum mentioned above.

In a random binary solid solution the probability that a given A atom will have exactly n B nearest neighbors is given by

$$P = \binom{8}{n} x^n (1-x)^{8-n}, \quad (2)$$

³ S. J. Pickart and R. Nathans, J. Appl. Phys. 5, 372S (1960).

where x is the atomic fraction of the B constituent. For each alloy we calculated a spectrum by summing the spectra for iron atoms with zero to eight aluminum neighbors, assuming for each type of iron atom an effective internal field given by Eq. (1), and a contribution to the total spectra proportional to the probability given by Eq. (2). In these calculations each peak has been given a full width of 0.5 mm/sec.

In calculating the predicted spectra it was assumed that the iron atoms in the foil were oriented at random. This assumption leads to an expected 3:2:1 pattern in the intensities. The data from the magnetically soft (both the magnetic anisotropy and magnetostriction are extremely small at this composition) 28% Al alloy did not fit, and it was surmised that it had spontaneously magnetized in the plane of the foil. This was checked by running two auxiliary measurements in which the absorption spectra of pure iron and of the 28% Al alloy were taken while placed in a strong magnetic field perpendicular to the direction of the γ ray. The intensity

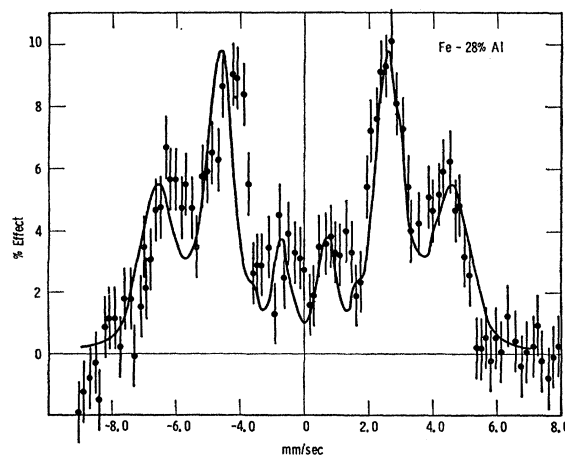


FIG. 5. Mössbauer spectra of iron-28 atomic percent aluminum alloy.

of the peaks in pure iron changed, as expected, to a 9/4:3:3/4 ratio. (The reason for this odd method of writing 3:4:1 is to preserve the normalization to the case of random orientation.) However the spectrum from the 28% Al alloy was the same as with no applied magnetic field. Therefore in calculating the solid curve for this alloy, 9/4:3:3/4 intensity ratios were assumed.

DISCUSSION

The agreement between the calculated curves and the experimental data is sufficiently good that we regard this model, in which the moment per iron atom depends only on the number of aluminum nearest neighbors, as adequate for the present level of experimental accuracy. Our results, however, do not provide a sensitive test of the exact functional relationship assumed [Eq. (1)], particularly in the range of large n . Our experiments were limited to the iron rich end of the diagram and the contribution to the spectra of iron

atoms with many aluminum neighbors was quite small. It also seems likely that second and more distant neighbor interactions must have some influence on the internal field, but since the natural width of the peaks is greater than the peak shifts due to the change of one nearest neighbor, the additional blurring due to second neighbor effects would be very difficult to see. Further measurements, including the effects of varying local order, as well as composition, may provide more detailed information about the relation between the local environment of an iron atom and the magnetic field at its nucleus.

The absence of observable broadening in the iron-cobalt and iron-nickel systems⁴ is not inconsistent with the model used here. The variation of internal field with composition in these systems is sufficiently small that the broadening due to varying microenvironments would be negligible.

⁴ C. E. Johnson *et al.*, Phys. Rev. Letters **6**, 450 (1961).

Determination of Contributions to the Residual Resistivity of Gallium at 4.2°K*

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Resistivity measurements have been carried out on single-crystal wires of high-purity gallium in the temperature range of 1.27° to 43°K, and also at 4.2°K on gallium with added impurities, and with varying wire diameter. The last measurements indicated the electron mean free path to be 1.2 mm at 4.2°K at a resistivity of about 3×10^{-22} esu, implying that the effective number of free electrons per atom in gallium is 0.2. Diffuse surface scattering was found to be an important scattering mechanism in wires of high-purity gallium at 4.2°K, and its contribution to the ratio of resistivity at 4.2 to 295°K in a 1-mm diam crystal is 1.5×10^{-5} . The temperature measurements indicated that no resistivity minimum occurs, and also that along the b axis, the lattice scattering contributes 0.4×10^{-5} to the resistivity ratio. The effect of grain boundaries on the resistivity ratio is negligible. The presence of as little as one atomic part per million of impurities such as Cu, Ag, Zn, Tl, Ge, Sn, Pb, and As can be detected by residual resistivity measurements.

I. INTRODUCTION

THERE are four main contributions to the resistivity of a metal, namely scattering of electrons from the lattice ρ_L , structural defects ρ_D , impurities ρ_I , and the surface ρ_S . To a first approximation, these contributions are independent of each other, and are connected by a simple additive relationship. The effect of lattice scattering, while dominant at room temperature, decreases with decreasing temperature. However, according to Matthiessen's rule, the effect of impurity scattering in metals is approximately temperature independent. The present research is concerned with determining the effect of each of the above contributions

in gallium by means of low temperature resistivity measurements.¹

Measurements have previously been reported on the variation of resistivity of gallium with crystallographic orientation and with temperature.^{2,3} The latter measurements have been repeated with gallium having over an order of magnitude fewer impurities, and the previously reported $T^{4.4}$ behavior of resistivity³ at low temperatures has been confirmed. However, in the present work, a more accurate value of the effect of lattice scattering has been derived, and in addition, the contribution due to specific impurities, structural defects, and diffuse

¹ L. R. Weisberg and R. M. Josephs, Bull. Am. Phys. Soc. **5**, 430 (1960).

² R. W. Powell, Proc. Roy. Soc. (London) **A209**, 525 (1951).

³ M. Olsen-Bar and R. W. Powell, Proc. Roy. Soc. (London) **A209**, 542 (1951).

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