HYPERFINE FIELD AND ATOMIC MOMENT OF IRON IN FERROMAGNETIC ALLOYS

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Mott and Stevens[1] and Lomer and Marshall[2] have proposed models of the ferromagnetic alloys of the iron group metals, based on the assumption that for dilute alloys a rearrangement of electrons occurs around solute atoms only, while to a first approximation the electronic structure of the matrix atoms remains unaltered from that in the pure metal. Each atom carries a localized magnetic moment which contributes directly to the total saturation moment and to the magnetic part of the neutron scattering cross section, and indirectly to the hyperfine field H_n. Marshall[3] has shown that the hyperfine field in a pure ferromagnetic metal should be proportional to the magnetization. This has been confirmed experimentally for cobalt[4] and for iron[5] by varying the temperature, but the absolute agreement between theory and measurement is poor.[6] The Mössbauer effect[7] provides a method for measuring H_n for iron in alloys which may be used to test the localized models and to investigate the relation between hyperfine field and atomic moment.

We have measured the Mössbauer absorption spectrum at room temperature over the whole range of Fe-Co and Fe-Ni alloys for the 14.4-key γ radiation of Fe^{57}. The source was prepared by electroplating Co^{57} onto copper foil, followed by diffusion by annealing. Rapid electron spin exchange resulted in a single line which had the natural width associated with the lifetime of the emitting state: The line was shifted by 0.20 mm/sec with respect to the center of the iron spectrum. The alloys were prepared by arc-casting spectroscopically standardized materials supplied by Johnson Matthey, Ltd., and were cold rolled into foils about 1 mil thick. Alloys containing 30% or less iron were enriched in Fe^{57} by plating and annealing. Data for pure cobalt and nickel were obtained with Co^{57} sources plated onto foils of each metal, using stainless steel as a monoenergetic absorber.[8] Motion of the source was provided by a moving coil vibrator driven by an amplifier and a triangular wave generator. A moving iron transducer gave a voltage proportional to the source velocity, and this waveform was fed back to the input of the amplifier, so that the velocity of the source closely followed the input waveform. Counts were fed into a single-channel pulse-height analyzer to select the 14.4-kev radiation, and the output pulses were modulated with the velocity waveform and fed into a 100-channel kicksorter. The resulting spectrum[9] showed six lines arising from the Zeeman splitting of the nuclear levels of Fe^{57}, and the hyperfine field was computed from their separations. The spectra for the alloys showed no appreciable line broadening or shifts compared with the pure iron spectrum. Hence, the variations in hyperfine field due to local inhomogeneities are small (less than 3%), and there is no large change in s-electron density at the iron nuclei due to alloying.

The variation of the magnetic field at iron nuclei in the alloys, expressed as a fraction of the field in metallic iron, is shown in Fig. 1, where $H_n(x)/H_n(0)$ is plotted against the excess electron number x over that of iron. A remarkable feature is the general similarity in form with the corresponding region of the Slater-Pauling curve[10] for the saturation moments: For both alloy systems H_n and the saturation moment show a maximum near $x = 0.3$. Even for small additions of solute it seems that large changes in the hyperfine field of the iron atoms result, in contrast to the localized theories.

If it is assumed that the hyperfine field is proportional to the atomic moment in the alloys, then the moment on iron is given by $\mu(\mathrm{Fe}) = 2.22 H_n(x)/H_n(0)$ Bohr magnetons. The field on cobalt nuclei in Fe-Co alloys has been determined from low-temperature specific heat measurements by Arp, Edmonds, and Petersen,[11] and in contrast to the field on iron nuclei it shows no maximum but increases steadily from 217×10^3 gauss in pure cobalt to about 320×10^3 gauss in iron. From these data a curve for $\mu(\mathrm{Co})$ may be derived, taking the moment in pure cobalt to be 1.71 Bohr magnetons. If these moments are averaged so that $\bar{\mu} = (1-c)\mu(\mathrm{Fe}) + c\mu(\mathrm{Co})$, where c is the cobalt concentration, $\bar{\mu}$ is found to lie on a curve which is close to the Slater-Pauling curve.

There are no data on the hfs of nickel in Fe-Ni alloys, but Shull and Wilkinson[12] have measured the atomic moments in some of these alloys by neutron diffraction. For ordered Ni_3Fe they find $\mu(\mathrm{Fe}) = 2.8$, whereas our data, combined with the

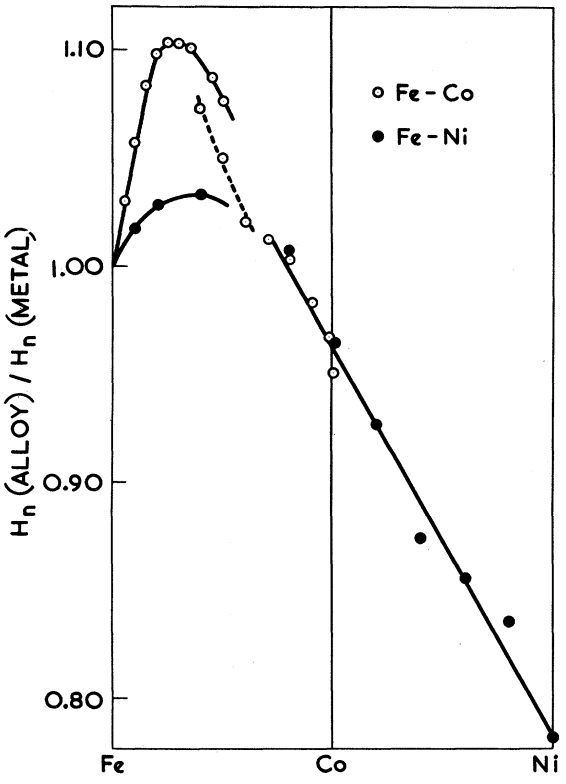

FIG. 1. The magnetic field at iron nuclei in Fe-Co and Fe-Ni alloys relative to the field in metallic iron, plotted as a function of electron number. The data in the range $Fe_{0.8}Ni_{0.2}$ to $Fe_{0.5}Ni_{0.5}$ where the Curie points are low have been corrected to take account of incomplete saturation at room temperature. Points for Co and Ni agree well with the results given by Wertheim.[8] Alloys near $Fe_{0.5}Co_{0.5}$ are very brittle and difficult to roll and the points on the dashed curve were taken with small and cracked specimens. Alloys were also prepared in this range by electroplating and they gave higher values for H_n which lie on the continuous curve.

assumption that atomic moment is proportional to H_n, give about 1.8. This implies that the proportionality between atomic moment and H_n is not strictly valid in alloys. The discrepancy could be explained by a contribution to H_n which depends on the nickel as well as the iron moments, e.g., if the component due to the conduction electron polarization were a function of the average moment $\bar{\mu}$. Since $\bar{\mu}$ for Ni_3Fe is smaller than that for iron and H_n is negative,[13] this explanation requires the polarization to be negative in accord with a suggestion of Anderson and Clogston[14] and with measurements of the field at tin nuclei in alloys with iron.[15] An estimate of the effect of such a term in the Fe-Co alloys shows that, owing to the smaller variation of $\bar{\mu}$ throughout the series, it would not destroy the agreement between $\bar{\mu}$ derived from hfs and saturation magnetization data.

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