SPIN WAVES AND STONER MODES IN IRON

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Résumé. — Le spectre d'onde de spin du fer a été mesuré selon les 3 directions principales de symétrie, par la diffusion inélastique des neutrons. On a trouvé que les relations de dispersion des ondes de spin augmentaient d'une façon presque quadratique selon la relation $E = Dq^2$, où D est égal à environ 260 meV. Å^2. L'intensité des ondes de spin diminue lentement jusqu'aux environs de 90 meV, puis décroît brusquement. On interprète la chute soudaine d'intensité, comme l'intersection de la courbe de dispersion de l'onde de spin avec une bande continue des excitations de Stoner.

Abstract. — The spin wave spectrum of iron has been measured in the three principal symmetry directions by neutron inelastic scattering. The spin wave dispersion relations were found to rise almost quadratically according to the relation $E = Dq^2$ where D is about 260 meV. Å^2. The spin wave intensity was found to decrease slowly until about 90 meV and then drop suddenly by more than an order of magnitude. The sudden decrease in intensity is interpreted as the intersection of the spin-wave dispersion curve with a continuum band of Stoner excitations.

The spin wave dispersion relations for iron have been measured in the three high-symmetry directions by neutron inelastic scattering. The measurements were performed on a triple-axis spectrometer at the High Flux Isotope Reactor.

Most of the measurements were made on a crystal of ^{54}Fe (4 % Si) 1 inch in diameter by 2 inches long. The ^{54}Fe isotope greatly reduced non-magnetic inelastic scattering events. Also since ^{54}Fe and Si have the same nuclear scattering lengths incoherent scattering was avoided. The isotope thus gave a much better signal to background ratio than could be obtained with pure iron. Nevertheless, a small crystal of pure iron was used to obtain some data, particularly at the lower energies.

The spin wave dispersion curves for Fe (4 % Si) are shown in figure 1. The spin wave spectra are almost quadratic and appear to be isotropic for the three symmetry directions. The spin wave spectra for pure iron rise slightly more steeply than those for Fe (4 % Si) and if one fits the lower energy spin waves with the relation $E = Dq^2$ it is found that D equals about 280 meV. Å^2 for pure iron compared to 260 meV. Å^2 for Fe (4 % Si). The spectra for Fe (4 % Si) falls below the quadratic dispersion law for higher momentum transfers and higher order terms in the dispersion law would be needed to fit the measured results.

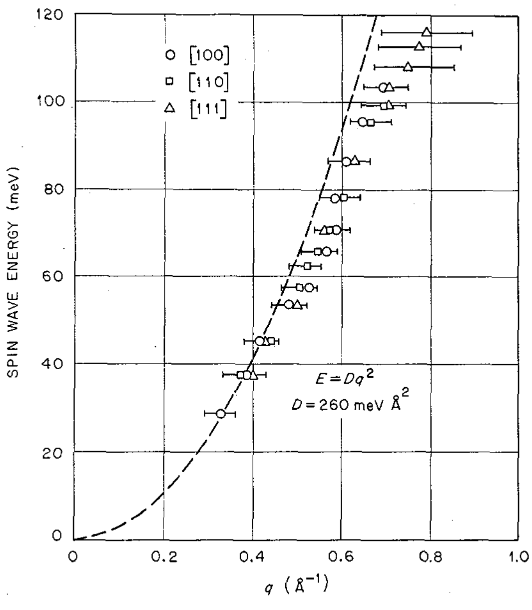

FIG. 1. — Spin Wave Dispersion Relations for Fe (4 % Si).

(*) Research sponsored by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

Previous measurements on Ni [1] have shown that the spin wave intensity drops suddenly at about 100 meV. This sudden decrease in intensity was interpreted as the intersection of the spin wave with a continuum band of Stoner excitations. We wished to see if similar effects were present in iron, thus spin wave intensity measurements were performed.

The number of neutrons $C(E_0\, q_0)$ scattered by a spin wave of energy E_0 and wave vector q_0 satisfies the following relationship.

$$C(E_0\, q_0) \sim \int\int \left[\frac{|F(\bar{K})|^2}{1 - \exp(-BE)}\right] \left(\frac{k'}{k_0}\right) \times \times W(q - q_0, E - E_0)\, \chi(qE)\, dq\, dE$$

where χ is the imaginary part of the atomic susceptibility, $F(K)$ is the form factor for momentum transfer K, k_0 and k' are the initial and final neutron wave vector respectively, and W is the resolution function. The resolution function was calculated by the technique suggested by Cooper and Nathans [2] and the spin wave peak shapes were obtained by numerical integration as the resolution function was passed through the dispersion surface. The peak widths calculated in this manner were in good agreement with the measured peak widths. No focusing of the spin waves is possible over the steep part of the dispersion curve so resolution effects give only a small variation in spin wave intensity. The incident neutron intensity was measured with a fission counter whose relative efficiency as a function of energy is known. All experiments were done with k' constant so that energy dependent effects of the analyzer could be neglected.

The spin wave intensity was obtained by dividing the spin wave peak height by the number of neutrons incident on the sample and removing the influence of energy dependent terms in the cross section such as the form factor and Boltzman factor. The peak height is thus directly related to the imaginary part of the atomic susceptibility. The spin wave intensity normalized to unity at zero energy transfer is shown in figure 2. The spin wave intensity falls off slowly with increasing energy until about 85 meV at which time the intensity decreases rapidly by more than an order of magnitude. We assume that this sudden decrease is caused by the intersection of the spin wave spectrum with a continuum band of Stoner excitations. The intersection point appears to be slightly different for the three symmetry directions, being highest in the [111] direction and lowest in the [100] direction. The intersection point agrees fairly well with the position of the Stoner excitations as determined by Thompson [3] from the energy bands for iron.

The experiment is difficult because very small intensity spin waves must be measured to determine the location of the Stoner continuum. The spin waves are also at high energies, and the number of neutrons in the reactor spectrum falls off rapidly at the high incident energies needed for the measurements. It is thus necessary to have a high flux reactor to make the measurements possible.

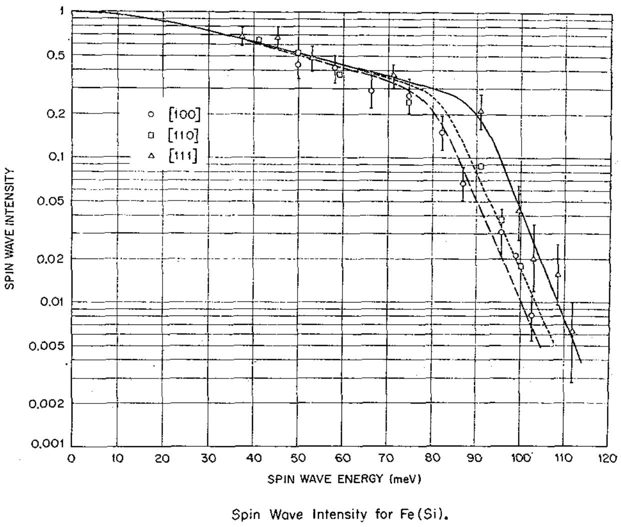

FIG. 2. — Spin Wave Intensity as a Function of Energy for Fe (4 % Si).

References

[1] MOOK (H. A.), NICKLOW (R. M.), THOMPSON (E. D.) and WILKINSON (M. K.), *J. Appl. phys.*, 1969, **40**, 1450.

[2] COOPER (M. J.), and NATHANS (R.), *Acta Cryst.* 1967, **23**, 357.

[3] THOMPSON (E. D.), and MOOK (H. A.), *J. Appl. phys.*, 1970, **41**, 1227.