Nuclear Magnetic Specific Heat in Two Ferromagnetic Iron Alloys*

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From the nuclear magnetic specific heat, measured at 1.6° to 4.2°K, $H_{\rm eff}$ at the Co nuclei in $Co_{0.3}Fe_{0.7}$ was calculated to be 312 koe, while $H_{\rm eff}$ at the V nuclei in $V_{0.33}Fe_{0.67}$ is 61 koe, or less. Both of these alloys are body-centered cubic and ferromagnetic. The large difference in the $H_{\rm eff}$ values may be associated with the fact that in $Co_{0.3}Fe_{0.7}$ the Co^{59} nucleus is located in an atom with appreciably polarized 3*d* electrons, while in $V_{0.33}Fe_{0.67}$ the V^{51} nucleus is the only abundant nuclide with a nuclear magnetic moment and the atomic moment of V is very small or zero. Since in ferromagnetic alloys the polarization of the core *s* electrons is expected to be much stronger in those atoms which do have polarized *d* electrons than in adjacent atoms which do not, the above results suggest that, in the alloys investigated, the dominant contribution to $H_{\rm eff}$ arises through Fermi contact interaction from the polarization of the core *s* electrons, as found for iron by Hanna *et al.*

IN a recent publication[1] Hanna *et al.* have shown that in iron the effective magnetic field at the Fe^{57} nucleus has a negative sign. They concluded from this result that in the effective field the predominating term arises through Fermi contact interaction from the polarization of the core *s* electrons. However, recent work by Samoilov *et al.*[2] shows that in dilute solutions of In, Sb, and Au in Fe the very high effective field at the nuclei of the diamagnetic solutes must be due to the polarization of the conduction electrons, as proposed by Marshall.[3] It is at present not possible to predict which contribution to the effective field will predominate in a given instance.

In ferromagnetic alloys the polarization of core *s* electrons may be expected to be much stronger in those atoms which do have polarized 3*d* electrons than in adjacent atoms which do not. The specific heat in the temperature range 1.6° to 4.2°K has been measured[4] for the following body-centered cubic alloys, both of which are ferromagnetic: $Co_{0.3}Fe_{0.7}$ and $V_{0.33}Fe_{0.67}$. The Curie temperatures of these alloys are approximately 970° and 750°C, respectively. Of the abundant nuclides in these alloys only Co^{59} and V^{51} have nuclear magnetic moments; the value for V^{51} is 5.148 μ_n, somewhat larger than that for Co^{59}, 4.648 μ_n. Any nuclear magnetic specific heat contributions in these alloys may be, therefore, attributed to the effective field at the Co or V nuclei. For $Co_{0.3}Fe_{0.7}$ we found[4] $H_{\rm eff}=312$ koe, in reasonable agreement with Arp *et al.*[5] However, for $V_{0.33}Fe_{0.67}$ the value of the effective field that may be calculated from the published low-temperature specific-heat data[4] is much smaller. This difference is significant, as it suggests that the most important contribution to $H_{\rm eff}$ in these alloys may be that arising from the polarization of the core *s* electrons.

TABLE I. Results of low temperature specific heat measurements with two bcc ferromagnetic iron alloys.

Alloy	$\gamma\times10^4$ (cal mole^{-1} deg^{-2})	$\beta\times10^4$ (cal mole^{-1} deg^{-4})	$\alpha\times10^4$ (cal mole^{-1} deg)	$H_{\rm eff}$ (koe)
$Co_{0.3}Fe_{0.7}$	4.2	0.046	7.1	312
$V_{0.33}Fe_{0.67}$	8.86	0.1169	0.375	60.9

Since the low value of $H_{\rm eff}$ calculated for $V_{0.33}Fe_{0.67}$ must very sensitively depend on the experimental errors in the specific heat measurements, new measurements were made using an improved procedure,[4] with a new alloy specimen homogenized by annealing at 1175°C in vacuum. The new results for $V_{0.33}Fe_{0.67}$ are given in Fig. 1. These may be compared with the results for $Co_{0.30}Fe_{0.70}$, reproduced for convenience in Fig. 2. Table I gives the coefficients α, β, γ for the two alloys in the equation $C=\gamma T+\beta T^3+\alpha T^{-2}$, calculated from the measured data by a least-squares method, as well as the effective field $H_{\rm eff}$, calculated from the coefficients α. Since, in the case of $V_{0.33}Fe_{0.67}$, the low α value obtained may be largely due to experimental errors, the effective

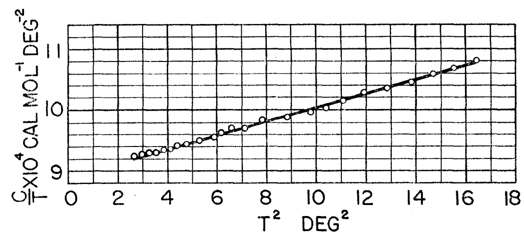

FIG. 1. Low-temperature specific heat of $V_{0.33}Fe_{0.67}$ (little, if any, nuclear magnetic specific heat contribution).

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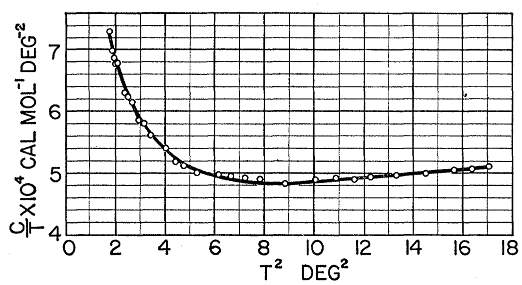

FIG. 2. Low-temperature specific heat of $Co_{0.3}Fe_{0.7}$ (large nuclear magnetic specific heat contribution).

field calculated from it is to be considered only as a maximum permitted by the data; the true effective field may be much smaller yet.

Our $Co_{0.3}Fe_{0.7}$ specimen was recently measured at temperatures below 1°K by Kurti and Exell.[6] Their results give $H_{eff}=301\pm8$ koe, a value probably more accurate than ours. However, the difference is not large, and it is certainly well within the limits of error of our value.

The large difference in the observed H_{eff} values for the two ferromagnetic alloys undoubtedly results from the fact that in $Co_{0.3}Fe_{0.7}$ the Co^{59} nucleus is located in an atom with polarized $3d$ electrons, while in $V_{0.33}Fe_{0.67}$ no atomic moment is connected with vanadium. The results for these alloys are, therefore, certainly consistent with the conclusion arrived at by Hanna *et al.*[1] for iron. It is apparent that in these cases the most important contribution to the effective field arises from the polarization of the core s electrons.

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[6] Private communication from Dr. N. Kurti.