to Ni films is in progress. Experiments using nickel will also have the advantage of allowing a direct observation of T_C since the thin-film samples are stable to approximately 500°C [$T_C(\infty)$ nickel = 358°C].

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DILUTE-ALLOY ANTIFERROMAGNETISM IN $Fe_{05}Au_{95}$ †

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The existence of magnetic transition in dilute random-substitutional alloys of Fe in Au has been demonstrated in a number of studies utilizing bulk-magnetization techniques[1-3] and the Mössbauer effect.[4,5] The data have been interpreted in terms of both ferromagnetic ordering and antiferromagnetic ordering. In this Letter we report Mössbauer studies on $Fe_{05}Au_{95}$ as a function of temperature and of an external magnetic field. Our studies show unambiguously that the ordering in this alloy is antiferromagnetic. From Mössbauer polarization measurements we find at temperatures well below the magnetic transition that even in the presence of external magnetic fields of 34 kOe the Fe spin orientation remains almost random, and there is little tendency toward spin orientation either parallel or antiparallel to the external field. Thus the possibility of ferrimagnetic as well as ferromagnetic ordering is excluded for this alloy. We believe this to be the most unambiguous demonstration to date of antiferromagnetism in a dilute random-substitutional alloy.

The magnetic-transition temperature in the Fe-Au system varies almost linearly with concentration for Fe concentrations up to about 15%, thereby indicating the existence of long-range interactions[5] with interaction strength $\sim 1/r^3$. At higher Fe concentrations the transition temperature increases rapidly with Fe concentration as short-range (ferromagnetic) ordering becomes dominant.[2,5] In the linear range the hyperfine magnetic field varies with temperature in a manner similar to that found in metallic Fe.[4] Bulk susceptibility measurements at higher temperature[1,3] follow a Curie-Weiss law and imply a moment per Fe atom

of 2 μ_B (Bohr magnetons) with negative paramagnetic critical temperatures at low Fe concentration (−3°K in $Fe_{005}Au_{995}$) and positive critical temperatures in more concentrated alloys (+23°K in $Fe_{05}Au_{95}$). Mössbauer studies in infinitely dilute Fe in Au yield an effective moment per Fe of 2 μ_B.[6] Henry[1] has measured the bulk magnetization at three temperatures in fields up to 95 kOe in $Fe_{05}Au_{95}$ and finds at 4.2°K a saturation magnetization of only 0.7 μ_B/Fe atom, suggesting antiferromagnetic ordering. Low-temperature susceptibility measurements on $Fe_{005}Au_{995}$ and $Fe_{01}Au_{99}$ show peaks characteristic of antiferromagnetic transitions.[3] Superparamagnetism associated with Fe clusters has been suggested as a possible explanation of the magnetization data.[7] However, this type of explanation seems unlikely to us because of the high solubility of Fe in Au at low concentration, and because none of the Mössbauer studies (including ours) shows any sign of a paramagnetic line at low temperatures such as should arise from isolated Fe atoms not in the clusters.

Our measurements were performed using a source of Co^{57} uniformly diffused through a 0.0005-in. foil of $Fe_{05}Au_{95}$ which was mounted inside a variable-temperature cell inside a superconducting solenoid. Fe^{57} 14-keV gamma radiation emerged from the cryostat along the magnet axis, thence through an unsplit resonant absorber (potassium ferrocyanide) and into a proportional counter and a velocity spectrometer. Zero-magnetic-field studies as a function of temperature showed our sample to undergo a magnetic transition at 23 ± 1°K. At 4.2°K the hyperfine field was −260 kOe (the negative sign is taken from Blum and Grodzins[8]).

A typical hyperfine-field spectrum obtained at 4.2°K and in zero external magnetic field is shown in Fig. 1(a). The six-line pattern is characteristic of magnetic ordering, but with line broadening amounting to about five times the ideal linewidth. Fig. 1(b) presents a spectrum obtained in an axial external field of 30.8 kOe. The similarity between the two curves is striking and unexpected, and explicitly demonstrates the presence of antiferromagnetic ordering in the sample (similar results have been obtained in a 34-kOe field). Nuclear selection rules prohibit gamma emission along the direction of the magnetic field acting at the nucleus. Ferromagnets in an external field exceeding the demagnetization field orient along

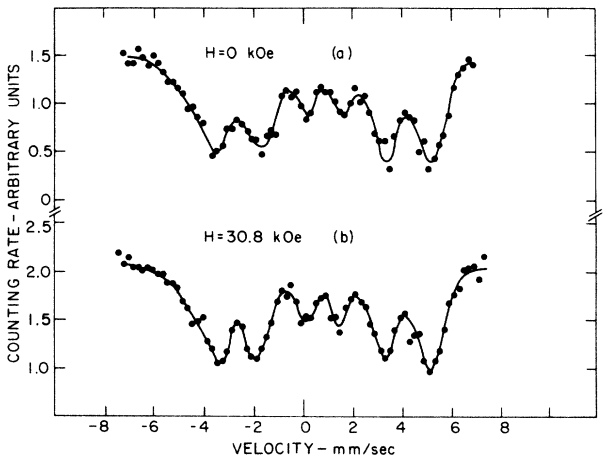

FIG. 1. (a) Mössbauer spectra in zero external field at 4.2°K in the magnetic alloy $Fe_{05}Au_{95}$ showing a hyperfine magnetic field of −260 kOe. (b) The same sample at 4.2°K in an axial field of 30.8 kOe. The similarity to the zero-field spectrum demonstrates (primarily from polarization considerations) antiferromagnetism in the sample and an almost random distribution of spin orientations.

the external field, and Mössbauer spectra observed along the field in such materials consist of four instead of six lines, with the second and fifth lines suppressed. Our finding that these lines remain almost unchanged in intensity in a field demonstrates that the external field does not appreciably alter the random spin orientation existing in zero field. We may thus immediately exclude the possibility of ferromagnetic or of ferrimagnetic ordering. These conclusions find further support in the absence of either line shifts or broadening in the external field, which would result from the external field adding to or subtracting algebraically from the hyperfine field. Rather, we have a situation in which a large number of spins make large angles with the external field. The effective field at the nucleus may be found as the vector sum of the hyperfine field and the external field. For external fields small in comparison to the hyperfine field this summation when averaged over almost random spin orientations results in slight line broadening and no line shift.

The details of the antiferromagnetic ordering in this alloy remain at present indeterminate. However, we would like to suggest the possibility that the system may well order as a canted weak ferromagnet. The possibility of such ordering in metallic alloys has been suggested by Moriya.[9] Henry's magnetization[1]

results at 4.2°K show a net moment of 0.35 μ_B/Fe atom in a field of 30.8 kOe, which could result from a bending of moments away from the direction of antiferromagnetic alignment. His zero-field moment of 0.04 μ_B per Fe atom is also typical of weak ferromagnetism. Effects similar to this have been observed in weak ferromagnets such as NiF_2 and Fe_2O_3.[9] A curious feature of $Fe_{05}Au_{95}$ is the positive paramagnetic Curie temperature of +23°K deduced from the high-temperature susceptibility[1] which is in precise agreement with the transition temperature we find from our Mössbauer measurements.

In an effort to study the region of the magnetic transition we have performed measurements with and without external fields at temperatures near to and above the transition temperatures. External fields are found to induce magnetization even above the transition, yielding families of hyperfine splitting vs temperature in various fields which are similar to those found in ferromagnetic $Fe_{2.65}Pd_{97.35}$ by Segnan, Craig, and Perisho.[10] At temperatures above about 10°K the hyperfine spectra broaden and it becomes impossible to distinguish lines and hence to make polarization determinations. This broadening is indicative of a spectrum of Fe-Fe coupling strengths depending upon the number of Fe neighbors in the random alloy. In order to obtain more detailed information in the region of the transition we are preparing to employ higher fields and to investigate more dilute alloys, which are not expected to show such severe line broadening. In addition, neutron-diffraction studies are planned in order to more fully characterize the magnetic structure in this alloy system.

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VISCOUS FLOW OF FLUX IN TYPE-II SUPERCONDUCTORS*

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It has been shown[1,2] that when the Lorentz driving force $(\vec{J}\times\vec{\varphi}_0/c)$ on the flux quanta in a current-carrying superconductor in a transverse magnetic field exceeds the depinning threshold, a voltage appears along the superconductor. An incremental resistivity ρ_f may be defined, independent of the amount of pinning. This voltage arises by induction from the driven flow of quantized flux vortices across the sample, opposed by viscous forces, assumed of the form $-f\vec{v}_\varphi$, where $\vec{v}_\varphi$ is the velocity of the vortex with respect to the sample. In that case, it has been shown[1,2] that this "flow" resistivity is

$$\rho_f = dE/dJ = B\varphi_0 f c^2, \tag{1}$$

which reduces the problem to analysis of the viscous drag coefficient f. The present note discusses the origin of f: the normal electron part, previously discussed by Volger, Staas, and van Vijfeijken,[3] as well as by Strnad, Hempstead, and Kim,[2] and a new mechanism which seems to dominate when $B \ll H_{c2}$.

Although (1) is conventionally derived for the geometry in which the applied field $\vec{H}_a$ is parallel to the surface of the strip, it is also val-