Magnetomechanical Ratios for Fe-Co Alloys

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(Received 20 November 1967)

Magnetomechanical ratios for four Fe-Co alloys were measured by the Einstein–de Haas method. Previous measurements on Fe, Co, Ni, and Fe–Ni and Co-Ni alloys are reviewed, thus completing magnetomechanical determinations for the binary alloys of these three ferromagnetic elements. Magnetomechanical ratios for these binary alloys are all different from those calculated from the effective atomic magnetic moments and angular momenta measured in experiments on the unalloyed constituents.

THE effective electronic orbital contribution M_0 and the effective electronic spin contribution M_s to the spontaneous magnetization M_t can be determined from the relations[1]

$$M_0/M_t=(2-g')/g' \text{ and } M_s/M_t=2(g'-1)/g', \quad (1)$$

where the magnetomechanical factor g' can be measured directly by the Einstein–de Haas[2] method or the Barnett[3] method, or it can be obtained from the ferromagnetic resonance[4] spectroscopic g factor and the relation (derivable from the work of Kittel[5] and of Van Vleck[6]) $g'^{-1}=1-g^{-1}$. The most accurate measurements appear to be those obtained by the Einstein–de Haas method.

Fe, Co, and Ni have g' values 4 to 8% less than 2 and, therefore, have orbital as well as spin contributions to their spontaneous magnetization.

We have previously determined[7–9] values of g' for Fe, Co, and Ni, and for Fe-Ni and Co-Ni alloys, using the Einstein–de Haas effect. The present paper reports results on Fe-Co alloys and thus completes the entire series of measurements.

PROCEDURES

An Einstein–de Haas experiment involves suspending a ferromagnetic rod as a torsional pendulum and impressing successive angular momentum changes on the system by a series of synchronous reversals of magnetization. Measurements of the resulting changes in pendulum amplitude (by means of a light, mirror, and scale) and in the magnetic moment enable one to determine the g' value for the sample being investigated. The experimental details used to obtain these values are outlined in an earlier paper[7] and some recent refinements are discussed in others.[8,9]

The probable errors quoted in this and in previous papers were calculated by deviations from the mean of several separate g' determinations. The absolute accuracy, as pointed out in an early paper,[7] is as good as the repeatability of the measurements.

The measurement of g' is related to the experimental parameters by the following equation:

$$g'=\frac{\Delta M-\Delta i\Sigma A}{\frac{1}{4}\pi I(e/m)d(PX)^{-1}-\Delta i\Sigma A},$$

where e/m is the charge-to-mass ratio of an electron, 1.7592×10^8 C g^{-1}, ΔM is the applied change in the magnetic moment of the pendulum, (C cm^2 sec^{-1}), d/X is the change in the angular peak-to-peak amplitude of the pendulum caused by ΔM, I is the moment of inertia of the pendulum (g cm^2), P is the period of the pendulum (sec), and $\Delta i\Sigma A$ is the change in the magnetic moment of the electrons in the coil which changes the magnetization (C cm^2 sec^{-1}).

The term $\Delta i\Sigma A$, which is subtracted from both the numerator and denominator of this equation, corrects for the angular momentum and magnetic moment of the electrons flowing in the magnetizing winding. This correction amounts to only about 1% and thus errors in $\Delta i\Sigma A$ are insignificant. Hence, the terms which contribute to the accuracy of the result are ΔM, I, P, X, and d. Of these quantities d, the change in scale amplitude is by far the most difficult to measure. The quantity d is an average determined over 480 cycles of the torsional pendulum. The pendulum integrates the ΔM impulses and also simultaneously integrates any uncompensated residual torque changes. Hence, elimination of the effect of torque changes can be assured. The effectiveness of this system for detecting extremely small torques has led to the recent discovery of an entirely new momentum transfer process in rarefied gases.[10]

An estimate of the accuracy of the quantities affecting these g' determinations is given in Table I. The absolute error in X is simply the accuracy to which we can measure 1600 cm. In determining P we measure the time for 100 full swings, hence our accuracy depends on our ability to measure 3500 sec. To measure I, we compare the pendulum against carefully made standards from which the moments of inertia were obtained by

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TABLE I. Summary of probable errors.

Parameter	Order of magnitude	Probable error (%)
d	0.1 cm	± 0.05
X	1600 cm	± 0.01
P	35 sec	± 0.01
I	200 g cm^2	± 0.01
ΔM	45000 C cm^2 sec^{-1}	± 0.02

accurate weighing and dimensional measurements. ΔM is obtained by comparing the pendulum with a carefully made air-coil standard. The dimensions of the coils were obtained from over 1000 micrometer readings having an accuracy of one part in 5000.

RESULTS ON Fe-Co ALLOYS

The g' values shown in Table II [11] were obtained using cast and ground cylindrical specimens 1.5 cm in diam and 22 cm long. The Fe and Co used had a nominal purity of 99%. Specific chemical analysis of the alloys for Ni indicated 0.18% by weight. Each g' value is the average of four measurements and each measurement was obtained on a different day using the experimental procedures described in Ref. 7.

SUMMARY OF RESULTS ON BINARY ALLOYS OF Fe, Co, AND Ni

In Fig. 1 we have summarized these magnetomechanical measurements by plotting g' values as a function of the effective atomic number Z. Although g' values tend to be smaller for higher Z, there appears to be no simple general relationship.

Assuming that the effective magnetic moments and angular momenta of the atoms have the values in an alloy which are characteristic of the unalloyed metals, an effective g' value can be easily determined. Such a consideration gives

$$g_{\text{eff}}' = \frac{X + k(1-X)}{X/g_A' + k(1-X)/g_B'},$$

TABLE II. g' factors for Fe-Co alloys. Probable error of these g' values estimated as ± 0.002. Ni content of these alloys, 0.18%.

Composition (weight)	g'
Fe	1.919
0.20 Co 0.75 Fe	1.918
0.50 Co 0.50 Fe	1.916
0.75 Co 0.25 Fe	1.902
0.90 Co 0.10 Fe	1.862
Co	1.838

[11] Data taken at Kettering Magnetics Laboratory, Oakland University, Rochester, Mich.

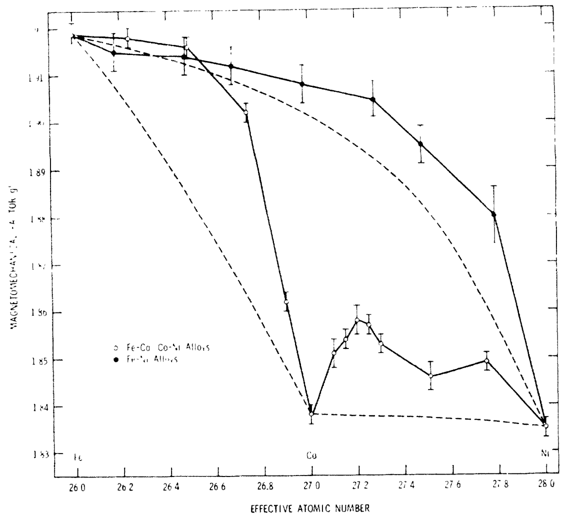

FIG. 1. Summary of g' factors for Fe, Co, Ni, and their binary alloys. The dashed lines are computed with the assumption that the g' values are simply the ratio of the effective atomic magnetic moments and the angular momenta measured in experiments on the unalloyed constituents.

where

$$X = \frac{\text{total number of } A \text{ atoms}}{\text{total number of atoms}},$$

$$k = \frac{\text{magnetic moment per atom of } B}{\text{magnetic moment per atom of } A},$$

$$g_A' = \text{magnetomechanical factor for } A \text{ atoms},$$

and

$$g_B' = \text{magnetomechanical factor for } B \text{ atoms}.$$

Values determined in this way are shown by the dashed curves in Fig. 1. The measured values are always larger. We therefore conclude that these atoms in binary alloys produce either smaller average orbital contributions or larger average spin contributions to the net magnetization than do these same atoms in the unalloyed metals. This conclusion is strengthened by neutron diffraction studies[12] which show that the average magnetic moment[5] of the individual iron atoms increases as cobalt is added to a binary alloy of Fe-Co from zero to 70%, while the magnetic moment of the cobalt atoms remains fixed.

Values of M_0 and M_s obtained using these data are discussed in the following paper.[13]

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