JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN VOL. 17, SUPPLEMENT B-I, 1962
PROCEEDINGS OF INTERNATIONAL CONFERENCE ON MAGNETISM AND CRYSTALLOGRAPHY, 1961, VOL. I

Magnetomechanical Determination of Gyromagnetic Ratios

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Gyromagnetic ratio experiments have been conducted in an isolated laboratory in which magnetic field levels can be held below 10^{-5} oersteds. g' determinations have been made for 19 different ferromagnetic materials.

Introduction

There are two converse magnetomechanical effects which can be used to determine gyromagnetic ratios; magnetization by rotation (the Barnett effect) and rotation by magnetization (the Einstein - deHaas effect). Both methods are subject to many difficulties but experimenters have agreed that the Einstein-deHass effect is most likely to yield reliable results.

In Einstein-deHaas experiments one changes the magnetic moment of a delicately suspended sample and observes the resulting change in angular momentum about the magnetic axis. Obtaining significant results depends on the successful elimination of a wide variety of disturbing torques, the most important of which have their source in coupling with external magnetic fields. Hence reduction of surrounding fields to an absolute minimum is very important. This requires the utilization of an isolated laboratory carefully constructed of nonferromagnetic materials. It also requires a neutralizing coil system capable of producing a variable and directable field of high homogeneity. The coil system for accomplishing this is shown in Fig. 1. The actual experiments are carried out in an evacuated chamber located at the center of this coil system. A sectional drawing of this chamber is shown in Fig. 2. The ferromagnetic sample is placed in the hollow winding of the torsional pendulum centrally located in this chamber. The period is about 30 seconds, damping is small, and readings of torsional deflection are made to 10ths of mm at the end of a 17 meter light beam.

Precautions are taken to eliminate electrostatic disturbance, to prevent amplitude changes resulting from microseismic earth motion and to eliminate asymmetric torques resulting from current reversal through the suspension. Torques caused by uncompensated fields are also allowed for by making observations at various azimuthal positions.

In obtaining data a system of resonance is used in which the magnetizing current is reversed at the time at which the pendulum crosses the center of its swing. Both increasing and decreasing amplitudes are observed so that the effects of damping can be

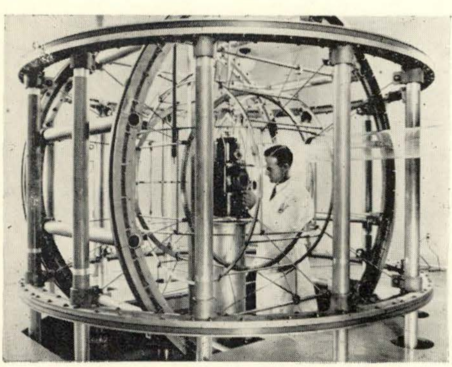


Fig. 1.

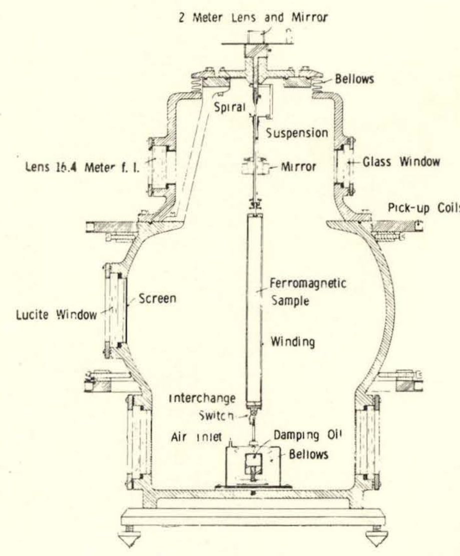


Fig. 2.

allowed for.

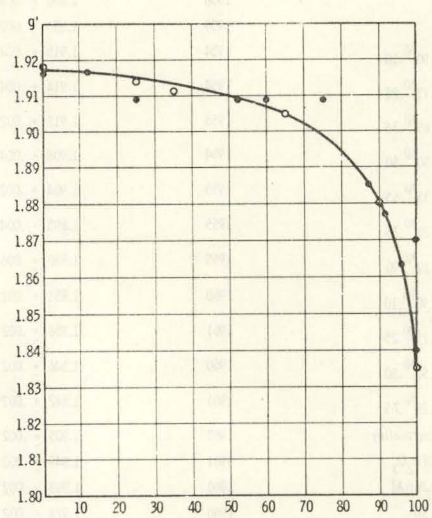
Separate measurements are required to determine magnetic moment changes, the moment of inertia and period of the pendulum, and the length of the optical arm.

Results

Measurements of g' have been made for Fe, Co, Ni, and for a variety of ferromagnetic alloys and compounds. One of the major experimental objectives has been the comparison of the magnetomechanical factor g' with the spectroscopic splitting factor g obtained by ferromagnetic resonance. It appears that the Kittel-Van Vleck relation $1/g+1/g'=1$ has been experimentally verified as shown in Figs. 3 and 4.

FERROMAGNETIC RESONANCE EXPERIMENTS					MAGNETOMECHANICAL EXPERIMENTS
MATERIAL	INVESTIGATORS	YEAR	g	$\frac{g}{g-1}$	g'
Fe	Bagguley	1953	2.16	1.86	
	Barlow, Standley	1956	2.09	1.92	
	Asch	1959	2.09	1.92	
	Rodbell	1959	2.05	1.95	
			Average	1.91	1.92
Co	Bagguley	1953	2.23	1.81	
	Asch	1959	2.18	1.85	
			Average	1.83	1.85
Ni	Bloembergen	1950	2.20	1.83	
	Young, Uehling	1953	2.28	1.78	
	Bagguley, Herrick	1954	2.22	1.82	
	Standley, Reich	1955	2.19	1.84	
	Reich	1956	2.21	1.83	
	Meyer	1958	2.17	1.85	
	Asch	1959	2.17	1.85	
			Average	1.83	1.84
Fe Ni	Hoskins, Wiener	1954	2.13	1.88	
	Asch	1959	2.10	1.91	
			Average	1.90	1.91
Co Ni	Asch, Meyer	1959	2.18	1.85	1.84
Supermalloy	Bloembergen	1950	2.12	1.89	
	Young, Uehling	1953	2.07	1.93	
			Average	1.91	1.91
Cu_2Mn Al	Yager, Merritt	1949	2.01	1.99	1.99
Mn Sb	Adam, Standley	1952	2.10	1.91	1.98
$NiO \cdot Fe_2O_3$	Yager et. al.	1950	2.19	1.84	
	Yager, Galt, Merritt	1955	2.19	1.84	
			Average	1.84	1.85

Fig. 3.



o Points obtained by G. G. Scott using Einstein - de Haas effect.

• Factor $\frac{g}{g-1}$ from g values obtained by Georges Asch using ferromagnetic resonance. Comptes Rendus 249, 1483, (Oct. 1959)

Fig. 4.

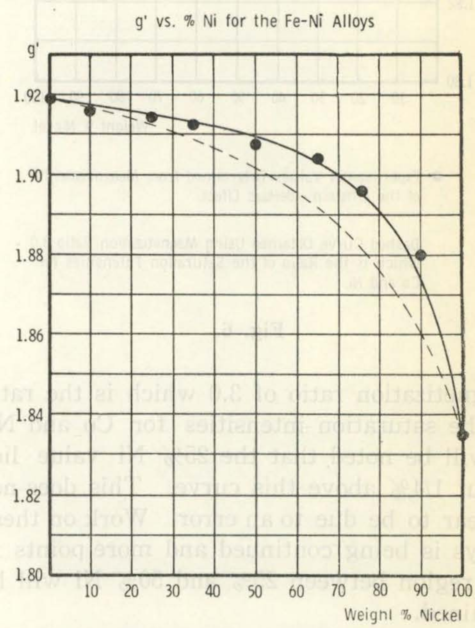
For alloys of the three ferromagnetic elements effective g' values can be calculated if it is assumed that the individual g' values and magnetizations per atom are the same as for the constituent metals and that the component atoms have their magnetic moments parallel throughout each domain. The following expression is thus obtained:

$$g'_{eff}=\frac{x+k(1-x)}{x/g_1'+k(1-x)/g_2'},$$

where x=fractional part of element #1

$$k=\frac{\text{saturation intensity of element \#2}}{\text{saturation intensity of element \#1}}.$$

This is similar to the expressions developed by Tsuya[1] and Wangsness[2]. Although such an expression does produce an approximate g' value for an alloy, experiment indicates



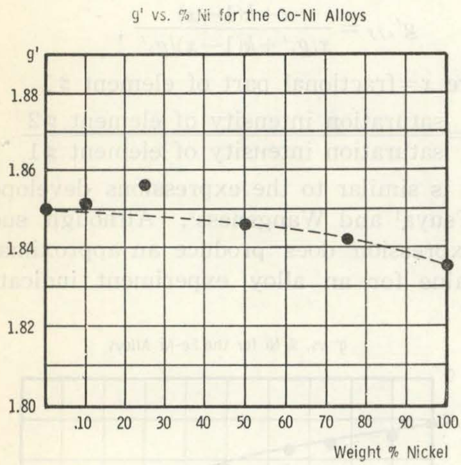
● Experimental Values Determined by G. G. Scott from Measurements of the Einstein-deHaas Effect

Dashed Curve Obtained Using Tsuya-Wangsness Relation, With Magnetization Ratio of 4.0 Which is the Ratio of the Saturation Intensities for Fe and Ni.

lid Curve Obtained Using Magnetization Ratio of

Fig. 5.

that the above assumptions constitute an over-simplification of the conditions actually existing. Fig. 5 shows results obtained for the FeNi alloy series. The dashed curve was obtained using the Tsuya - Wangsness relation with a magnetization ratio of 4.0 which is the ratio of the saturation intensities for Fe and Ni. To obtain the solid curve which fits the experimental data a magnetization ratio of 8.2 was required. Fig. 6 shows results for the CoNi alloy series. In this case a somewhat different situation exists. Here the dashed curve was plotted using a



● Experimental Values Determined from Measurements of the Einstein - deHaas Effect.

Dashed Curve Obtained Using Magnetization Ratio 3.0 Which is the Ratio of the Saturation Intensities for Co and Ni.

Fig. 6.

magnetization ratio of 3.0 which is the ratio of the saturation intensities for Co and Ni. It will be noted that the 25% Ni value lies about 1/4% above this curve. This does not appear to be due to an error. Work on these alloys is being continued and more points in the region between 25% and 50% Ni will be obtained.

Experiments have also been conducted on two ferromagnetic alloys of manganese. The g' value for the Heussler alloy Cu_2MnAl was given by Barnett as 2.00. In the present experiments two different rods of this alloy were used with no significant difference between results. The average of all these experiments on Cu_2MnAl gave a g' value of 1.993. Although this value departs only 0.35% from the spin only value for g' the precision is such that it is thought unlikely that orbital quenching is complete.

Experiments were also conducted on a rod of manganese antimonide (MnSb). The g' value of 1.978 indicates a considerably larger orbital contribution to the net magnetization for this alloy.

Work on ferromagnetic compounds has been limited thus far to nickel ferrite and pyrrhotite.

The ferrite rod was made with considerable care so as to assure the stoichiometry of NiO Fe_2O_3. The g' value of 1.849 indicates that the net magnetization in this material is largely due to the Ni^{++} ions as in the Néel model.

The pyrrhotite sample was fabricated at the University of Strasbourg under the direction of Dr. André Meyer. This is an extremely difficult material on which to make gyromagnetic ratio measurements. Not only is it very weakly ferromagnetic, but it is also subject to relatively large field coupling

SUMMARY OF g' VALUES

Obtained by G. G. Scott Using Einstein-de Haas Effect

Material	Year Obtained	g'
Fe	1959	1.919 ± .002
Co	1956	1.850 ± .004
Ni	*1959	1.835 ± .002
$Fe_{.90}Ni_{.10}$	1954	1.915 ± .004
$Fe_{.75}Ni_{.25}$	1954	1.914 ± .004
$Fe_{.65}Ni_{.35}$	1955	1.912 ± .002
$Fe_{.50}Ni_{.50}$	1954	1.908 ± .004
$Fe_{.35}Ni_{.65}$	1955	1.904 ± .002
$Fe_{.25}Ni_{.75}$	1955	1.895 ± .004
$Fe_{.10}Ni_{.90}$	1955	1.880 ± .006
$Co_{.90}Ni_{.10}$	1960	1.851 ± .002
$Co_{.75}Ni_{.25}$	1961	1.856 ± .002
$Co_{.50}Ni_{.50}$	1960	1.846 ± .002
$Co_{.25}Ni_{.75}$	1961	1.842 ± .002
Supermalloy	1960	1.905 ± .002
$NiOFe_2O_3$	1961	1.849 ± .002
Cu_2MnAl	1960	1.993 ± .002
MnSb	1960	1.978 ± .002
Pyrrhotite	1960	1.9 ± 15%

*Average of four experiments - 1951, 1953, 1955, 1959

Subscripts used with alloys refer to weight percentages.

Fig. 7.

torques because of its highly anisotropic nature. As used, this pyrrhotite sample produced a net torque about 1/400 of that obtained for Fe. These experiments on pyrrhotite resulted in a g' value of $1.9 \pm 15\%$.

The only other known measurement on pyrrhotite was made in 1935 by Coeterier[3] who obtained a g' value of .63. This extraordinary value can not be explained on the basis of recent pyrrhotite models. Coeterier obtained the correct value for Fe with his same equipment. However, in view of our experience with the extremely large coupling torques of pyrrhotite this in itself does not appear to be a valid comparison.

Fig. 7 gives a summary of all of the g' measurements which have been made by the author to the present time.

Acknowledgment

The author would like to pay tribute to the late Charles F. Kettering who initiated these experiments at General Motors and also to thank the Kettering Foundation for making available the highly specialized laboratory facility required.

References

1 N. Tsuya: Prog. Theor. Phys. **7** (1952) 263.
2 R. K. Wangsness: Phys. Rev. **91** (1953) 1085.
3 F. Coeterier: Helv. Phys. Acta **8** (1935) 522.

DISCUSSION

J. SMIT: Two relationships between g and g' have been proposed

(a) $g+g'=4$ (b) $1/g+1/g'=1$

These two equations differ in terms of order $(g-2)^2$. The theory of Kittel and Van Vleck actually gives

$$\Delta S_z/g+1/g'=1$$

in which ΔS_z is near to unity. It can be shown when using a model with a non-degenerate ground state with all relevant excited states at a distance ε that Eq. (b) generally is a better approximation to the exact equation than is (a). In fact Eq. (b) gives the best agreement with the experiments.

L. R. BICKFORD: It should be of interest to measure g' for a ferrite with its compensation temperature near room temperature.

G. G. SCOTT: This was suggested by Dr. Van Vleck at a symposium on g factors held last February at Dayton, Ohio. We hope to be able to do such an experiment in the near future.