to counter detection. Curve B is obtained from a modified Waller-Hartree approximation: the contribution of the core electrons is calculated from Eq. (2), using the James and Brindley values for $|f_{jj}|^2$ for the core electrons of a free aluminum atom and the values of $\sum\sum_{j\neq k}|f_{jk}|^2$ calculated for a neon atom by Harvey, Williams, and Jauncey,[13] and to this is added the contribution of the three conduction electrons, calculated from Eq. (3). The difference between these two calculated curves for values of $(\sin\theta)/\lambda>0.28$ is due exclusively to the exchange term in the Waller-Hartree expression. Its inclusion in this case reduces the intensity of the Compton scattering by as much as 20%, an amount which is certainly not negligible. Even greater differences appear at the lower angles.

The measured values for the Compton scattering are not fitted by either of the two calculated curves. The usual calculation, Curve A, is uniformly too high, the discrepancy being as much as 25%. The modified Waller-Hartree calculation shows much better agreement, but there are still significant differences at the higher values of $(\sin\theta)/\lambda$. While these differences may be due in part to the approximations employed in the calculation, such as using the exchange term calculated for neon, they may also arise in part from the band structure effect discussed above.

In summary, none of the present theoretical expressions for the intensity of the Compton scattering are reliable over a reasonable range of angles for the case of aluminum. The usual expression is seriously in error over the entire range of angles investigated, and the modified Waller-Hartree expression, while reasonably accurate at the low angles, shows significant errors at the higher angles. The source of these errors is probably to be found in the incomplete inclusion in the theory of the effects of the lattice periodicity on the electronic wave functions. Thus, if an accurate knowledge of the intensity of the Compton scattering is required, at present one must rely only on experimental measurements.

PHYSICAL REVIEW VOLUME 103, NUMBER 3 AUGUST 1, 1956

Gyromagnetic Ratios of the Iron-Nickel Alloys

G. G. SCOTT
Research Staff, General Motors Corporation, Detroit, Michigan
(Received March 1, 1956; revised version received April 27, 1956)

Measurements by magnetomechanical experiments show that the gyromagnetic ratios for the alloys of the iron-nickel series undergo changes for low values of the induced magnetic intensity. This leads to a high- and a low-intensity value for g' for each metal. Two distinct curves of g' *vs* percent nickel are thus obtained. Nine different rods were used in which the content of nickel in iron varied from 0% Ni to 100% Ni.

INTRODUCTION

IN these experiments on the iron-nickel alloys, nine different rods were used[1] in which the content of nickel in iron varied from 0% Ni to 100% Ni. The results for the 100% Fe and 100% Ni rods have already been reported.[2] The same dependence of g' on the intensity of magnetization, noted for Fe and Ni in the above references, was observed also for the alloys of these metals.

Each of the iron-nickel rods, after casting, was inspected by x-ray to make certain of the absence of voids. The rods were then ground to size and annealed for two hours in dry hydrogen at 2000°F. They were then furnace cooled. These alloys contained impurities of a few tenths of one percent; mostly Mn, Al, or C. Each rod was wound with its own magnetizing winding and supported in the apparatus as a torsional pendulum as has been previously described.[2,3]

[1] The Fe-Ni rods were cast by the metallurgical department of the General Motors Research Staff.
[2] G. G. Scott, Phys. Rev. **99**, 1241 and 1824 (1955).
[3] G. G. Scott, Phys. Rev. **82**, 542 (1951).

RESULTS

The following relationship was used to calculate the gyromagnetic ratio from the experimental data. Factors which are common to all of the rods are given values in the list of symbols. The other factors were determined independently for each rod. For the method of obtaining the data, see reference 2.

$$\rho\frac{e}{m}=\left(\frac{\pi Id}{4PXkm/e}-2i_e\sum A_e\right)\bigg/(M_e-i_e\sum A_e),$$

where ρ = gyromagnetic ratio (g coul^{-1}), I = moment of inertia (g cm^2), d = (double) amplitude change per reversal of i_e (cm), P = period of torsional pendulum (sec), X = optical length = 1576.9 cm, k = phase angle constant = 0.99941, m/e = mass-charge ratio of electron = 5.6844×10^{-9} g coul^{-1}, i_e = magnetizing current (amp), $\sum A_e$ = winding constant (cm^2), and M_e = magnetic moment (rod and winding) (amp cm^2).

Table I gives a condensation of the data taken for the 35% Ni 65% Fe rod. Each value of d given in this table

TABLE I. Condensed data for determination of the gyromagnetic ratios for the alloy 35% Ni, 65% Fe.

I g cm²	i_e milliamp	M_e amp cm²	P sec	d cm	$\rho e/m$
206.76	2.0006	10893	27.762	0.017790	1.0526
206.76	2.0005	10893	27.749	0.017800	1.0537
206.85	2.0000	10931	27.401	0.017595	1.0516
206.85	2.0001	10932	27.401	0.017646	1.0547
206.76	4.0012	22050	27.760	0.035889	1.0492
206.76	4.0005	22046	27.751	0.035941	1.0514
206.85	4.0000	22098	27.405	0.035401	1.0470
206.85	4.0000	22098	27.405	0.035479	1.0489
206.76	7.0020	38916	27.759	0.063231	1.0475
206.76	7.0014	38913	27.754	0.063085	1.0453
206.85	7.0000	38957	27.410	0.062487	1.0477
206.85	10.0013	55731	27.422	0.089320	1.0464
206.85	10.0007	55728	27.422	0.089242	1.0455
206.85	12.0007	66757	27.424	0.106920	1.0456
206.85	12.0000	66753	27.424	0.107073	1.0472
	Winding constant	$\Sigma A_e = 78907$ cm²			

is the result of 240 individual observations of amplitude change. Data obtained for the other six alloys in the series were similarly condensed. All of the results are summarized in Table II.

Data on these alloys were obtained over a period of nearly two years. The rods used can be divided into two groups. The first group contains three different alloys; 10% Ni, 50% Ni, and 75% Ni. For this group only enough data were obtained to determine the gyromagnetic ratio at low values of the induced magnetic intensity.

The second group contains four different alloys; 25% Ni, 35% Ni, 65% Ni, and 90% Ni. For this group sufficient data were obtained to show the field dependence of the gyromagnetic ratios. Data for each rod of this group were taken at intervals of over one year and good agreement between repeated sets was obtained. The 25% Ni rod had a Curie temperature of about 100°F. When current values greater than 6 milliamperes were used, the heat dissipated by the winding drove the temperature of the ferromagnetic material up to a value where the temperature coefficient of permeability was very high. In this work, the changes in angular momen-

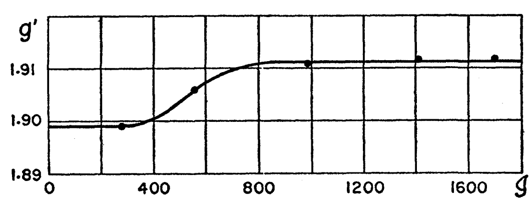

FIG. 1. Plot of g' *vs* average induced magnetic intensity ($\mathcal{G}$) for 35% Ni, 65% Fe rod.

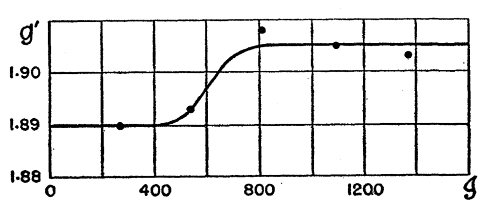

FIG. 2. Plot of g' *vs* average induced magnetic intensity ($\mathcal{G}$) for 65% Ni, 35% Fe rod.

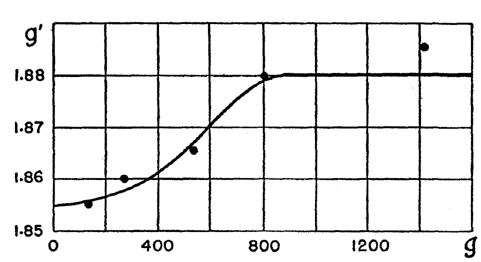

FIG. 3. Plot of g' *vs* average induced magnetic intensity ($\mathcal{G}$) for 90% Ni, 10% Fe rod.

TABLE II. Summary of results. Values of $\rho e/m$ and g' averaged for each value of magnetic intensity used in these experiments on the FeNi-alloy series.[a]

i_e	$\mathcal{G}$	$\rho e/m$	g'	δ	N
		10% Ni 90% Fe			
4.0	251.1	1.0547	1.8962	0.0008	2
7.0	473.3	1.0525	1.9003	0.0020	2
		25% Ni 75% Fe			
2.0	274.6	1.0551	1.8955	0.0007	4
4.0	551.0	1.0482	1.9081	0.0014	7
6.0	820.0	1.0448	1.9142	...	1
		35% Ni 65% Fe			
2.0	276.6	1.0532	1.8991	0.0008	4
4.0	559.6	1.0491	1.9063	0.0011	4
7.0	987.0	1.0468	1.9105	0.0009	3
10.0	1413.1	1.0460	1.9121	0.0006	2
12.0	1692.6	1.0464	1.9114	0.0010	2
		50% Ni 50% Fe			
4.0	554.3	1.0565	1.8931	0.0015	10
		65% Ni 35% Fe			
2.0	265.4	1.0582	1.8900	0.0031	4
4.0	537.4	1.0565	1.8930	0.0019	7
6.0	810.1	1.0483	1.9078	0.0006	2
8.0	1085.3	1.0499	1.9050	0.0035	2
10.0	1366.4	1.0510	1.9030	0.0007	2
		75% Ni 25% Fe			
4.0	483.8	1.0669	1.8745	0.0012	6
		90% Ni 10% Fe			
1.0	132.2	1.0780	1.8554	0.0044	5
2.0	265.4	1.0755	1.8597	0.0024	6
4.0	531.2	1.0718	1.8661	0.0008	11
6.0	802.5	1.0639	1.8799	0.0028	4
10.0	1414.5	1.0602	1.8864	...	1

[a] $\mathcal{G}$ = average induced magnetic intensity of rod, amp cm⁻¹. $\mathcal{G} = M_e - i_e \Sigma A_e / v$, where v = volume of rod, 38.88 cm³. N is the number of complete sets of data taken to determine the particular value of g'. Each set consists of eight runs, which number was required in order to eliminate systematic effects of damping, small uncompensated fields, and suspension torques. Each run consists of 30 consecutive observations of the torsional pendulum amplitude, taken as that amplitude was changed by consecutive angular momentum impulses. Each amplitude observation is obtained from 2 scale readings. δ = probable error in the value of g' computed from the deviations from the mean of the N values used. δ does not include the accidental error in the measurement of magnetic moment which was about 0.05%. Errors in measuring the moment of inertia, the period, and the optical length were negligible.

tum and the changes in magnetic moment, are correlated to changes in winding current by separate experiments in which the rod occupies two different positions for the two setups. Also, for a winding current of 12 milliamperes there was a difference of about 4°F between the equilibrium temperature values for the two positions. Since it would be difficult in this case to make temperature corrections to sufficient precision, all readings above 6 milliamperes were discarded for this alloy. Below 6 milliamperes, the temperature rise and the temperature coefficient of permeability for the 25% Ni rod were both negligible. The temperature coefficient of permeability for all other rods in the series was negligibly small for all of the operating temperatures used.

For each of the other three rods in the second group, five different values of magnetizing current were used. Data for each of these three alloys are plotted in Figs. 1–3. By referring to these figures, and also to the corresponding figures given in reference 2, it can be seen that the g' factor when plotted against the average induced magnetic intensity of the specimen has a constant value above about 800 amp cm^{-1}. At lower magnetic intensities g' drops down to a smaller value. Therefore, in plotting the data for the alloy series two values of g' were considered for each alloy. The first value, that on the upper plateau, was determined by averaging all of the individual values which were taken at induced intensities above 800 amp cm^{-1}. The second series of points was obtained by using, for each rod, the average of the g' values measured at the lowest magnetic intensity used in the experiments. The resulting curves are shown in Fig. 4.

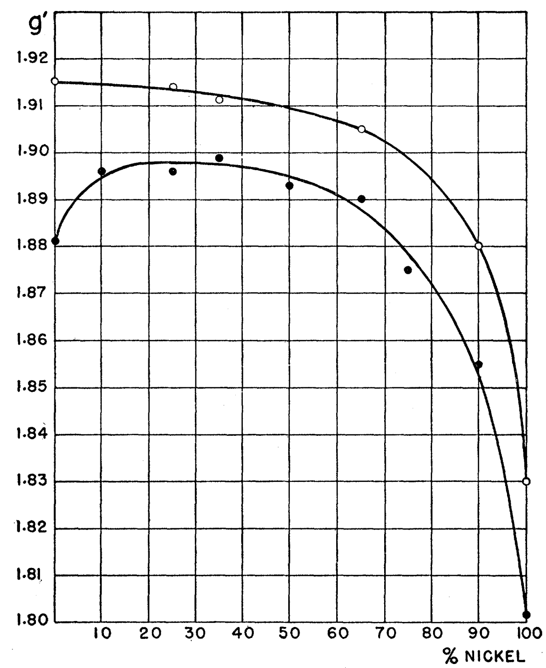

FIG. 4. Plot of g' *vs* percent nickel for the iron nickel alloy series. Open circles are the averages of all values taken above an induced magnetic intensity of 800 amp cm^{-1}. Solid circles are averages of all values taken at the lowest induced magnetic intensity used for the particular alloy.

CONCLUSIONS

The values of g' for iron, nickel, and all of the alloys of these two metals, undergo a change in weakly magnetized specimens. Above an induced magnetic intensity of 800 amp cm^{-1}, g' for each metal has a value which is not dependent on magnetization. Below 800 amp cm^{-1}, g' decreases to a value which checks the value expected from a consideration of recent work on ferromagnetic resonance.

Also it appears possible to obtain by magnetomechanical experiments, more precise determinations of g factors than is at present possible by ferromagnetic resonance techniques.

The author wishes to express his appreciation to the numbers of the General Motors Research Staff whose cooperation made this work possible.