Investigation of the Einstein–de Haas Effect for Cobalt and for the Co-Ni Alloys*

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Magnetomechanical measurements on cobalt gave a g' value of 1.838±0.003. This value for cobalt appears to be unaffected by changing from the hexagonal to the cubic phase, and is nearly the same as the value for nickel. Magnetomechanical measurements were also made on seven different alloys of the Co-Ni series. All of these alloys have g' values greater than that which characterize the constituent metals.

INTRODUCTION

THIS paper summarizes the results of a series of Einstein–de Haas experiments on cobalt and on cobalt-nickel alloys. These measurements were conducted in a special laboratory provided by the Charles F. Kettering Foundation. This facility has recently been moved from Dayton, Ohio to Oakland University, Rochester, Michigan, and some of the experiments in this series were conducted at this new location. The techniques used and the results of earlier magnetomechanical measurements have recently been reviewed.[1]

Briefly, the Einstein–de Haas experiment involves suspending a ferromagnetic rod as a torsional pendulum, and impressing angular-momentum changes on the system by reversals of magnetization. Many resonant increments must be added to the system if measurement accuracy is to be attained. If extraneous torque changes occur simultaneously with the momentum changes, it becomes of extreme importance to make magnetization reversals as the pendulum passes through the midpoint of its oscillation. Refinements have recently been made in the timing of these magnetization reversals so that the transit across center is now observed through a shutter which has been synchronized with the field reversals. This technique markedly reduces the effect of small uncompensated torques on the pendulum amplitude.

In our earlier work on cobalt,[2] measurements on different samples produced somewhat different values for g'. These differences were originally attributed to impurities in the samples. With the improved phasing of magnetization reversals these apparent differences have been eliminated.

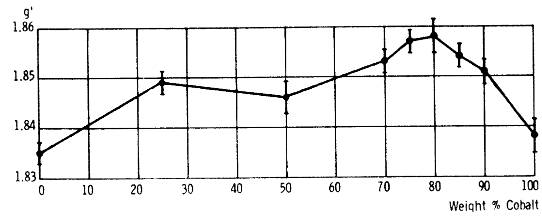

FIG. 1. g' values for Co-Ni alloy series.

RESULTS ON COBALT

Five different groups of experiments were conducted on three different samples of cobalt. The results are summarized in Table I. Samples 1 and 2 were in the form of rods supplied by the Kulite Tungsten Corporation and the International Nickel Company, respectively. Specimen 3 was a powder of face-centered-cubic cobalt prepared by a process described by Troiano and Tokich.[3] Transformation to the cubic phase was confirmed by x-ray diffraction studies. The gyromagnetic ratio for cobalt appears to be unaffected by

TABLE I. Summary of g' experiments for cobalt.

Specimen	g'	Number of angular momentum determinations
1[a]	1.830	6
2[b]	1.845	6
1	1.834	4
1	1.843	4[d]
31[c]	1.840	4[d]
Average	1.838±0.003	

[a] Rod supplied by Kulite Tungsten Company. Major impurities: 0.47% Ni, 0.20% Fe.
[b] Rod supplied by International Nickel Company. Major impurities: 0.93% Ni, 0.12% Fe, 0.22% Mn.
[c] Powder supplied by Matheson Company. Annealed so as to retain a large percentage of the cubic phase at room temperature. Major impurities: 0.2% Ni, 0.1% Fe.
[d] Data taken at Oakland University.

TABLE II. Summary of g' experiments for Co-Ni alloys. Rods cast by General Motors Research Laboratories. Fe content 0.1% to 0.2%.

Alloy		g'	Number of angular momentum determinations and probable error of mean
0.25 Co	0.75 Ni	1.849	3, 0.002
0.50 Co	0.50 Ni	1.846	6, 0.003
0.70 Co	0.30 Ni	1.853	5, 0.002
0.75 Co	0.25 Ni	1.857	3, 0.002
0.80 Co	0.20 Ni	1.858	6,[a] 0.003
0.85 Co	0.15 Ni	1.854	6, 0.002
0.90 Co	0.10 Ni	1.851	10, 0.003

[a] Data taken at Oakland University.

* Experimental work conducted at Charles F. Kettering Magnetics Laboratory, now located at Oakland University, Rochester, Michigan.

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[2] G. G. Scott, Phys. Rev. **104**, 1497 (1956).

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changing from the hexagonal to the cubic phase. The average of these five groups of experiments on cobalt resulted in a g' value of 1.838 ± 0.003. Corresponding Einstein–de Haas experiments on nickel[1] gave a value of 1.835 ± 0.002.

RESULTS ON Co-Ni ALLOYS

The results of experiments on seven different cobalt-nickel alloys are summarized in Table II, and the g' versus composition curve is displayed in Fig. 1. These alloys were cast in the form of rods by the Metallurgical Engineering Department of the General Motors Research Laboratories.

Since g' values for both Co and Ni are nearly the same, alloys of these metals form an interesting series for studying variations in g' with composition. It is noteworthy that all of these alloys have magneto-mechanical factors larger than the value which is characteristic of the constituents. This indicates a decrease in the orbital component of the magnetization as a result of alloying. The largest value for the series represents a decrease in the ratio of orbit to spin magnetization from 0.097 for both cobalt and nickel to 0.083 for the alloy 80% Co 20% Ni. This g' maximum occurs at the point where both the face-centered-cubic and the hexagonal phases coexist at room temperature.

A similar decrease in the orbital component of the magnetization was noted for the Fe-Ni alloy system.[1]

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Specific Heat of MnS through the Néel Temperature*

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The specific heat of α-MnS has been measured from 80 to 240°K. A sharply peaked transition has been observed giving a Néel temperature of 152 ± 0.8°K. These results indicate only one peak similar in shape to the usual antiferromagnetic behavior, and disagree with earlier work which reported other structure in this temperature region.

THE Néel temperature (T_N) of α-MnS (green, NaCl structure) has been reported by a number of workers[1–6] ranging from 139°K to 165°K. During the course of investigations at this laboratory of certain electrical and optical effects occurring near the Néel temperature, it became necessary to know this magnetic-transition temperature accurately. Also, if the disparity in reported values of T_N has been caused by individual sample differences, then it was necessary to determine T_N for the MnS material used in our studies. Because of the sharply peaked behavior of the specific heat at the Néel temperature, this property was chosen to pinpoint T_N, and an existing general-purpose cryostat was modified for the measurements. Results of these measurements help to clarify a puzzle caused by two structures in the specific-heat curve of Anderson[5] and discussed since by several authors.[4,6,7]

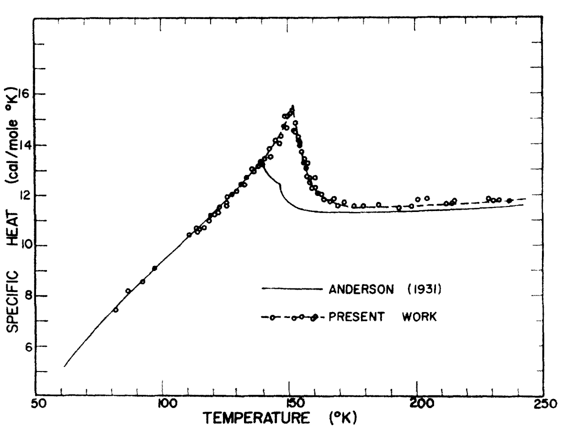

FIG. 1. Specific heat of α-MnS in the vicinity of the Néel temperature.

Powder samples of MnS were prepared by the method of Archer and Mitchell,[7] who emphasized the importance of careful elimination of oxygen from the sample. Oxygen contamination as determined by neutron-activation analysis[8] showed about 700 parts per million (ppm) of oxygen. About 10 g of this powder was pressed into a $\frac{1}{2}$-in.-diam pellet using 5 kbars of pressure. The resulting specific-heat sample had a density which was 87% of single-crystal density. The sample was suspended in a brass can whose temperature could be controlled between 78°K and 300°K by balancing the heat

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[8] Commercial service performed by General Atomic Division, General Dynamics.