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The Wiedemann Effect of the Binary System of Iron-Aluminium Alloys at High Temperatures*

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Synopsis

The Wiedemann effect was measured at high temperatures with annealed specimens of 13 Fe-Al alloys. With the addition of Al to Fe, the torsion increased at first gradually, but after reaching a maximum at the concentration of about 13 per cent Al it decreased rapidly. In alloy containing less than about 6 per cent Al it was similar to that of iron, while in the alloy containing more than about 6 per cent Al it was similar to that of "Alfer".

I. Introduction

Up to recent years very few research works have been reported on the Wiedemann effect of binary alloys excepting only a few treating Fe-Ni[1] alloys. The present authors[2][3] have measured the Wiedemann effect of the magnetostriction alloy "Alfer". Since then, measurements were made on the Wiedemann effect successively at high temperatures with annealed specimens of 13 Fe-Al alloys.

II. Measurements and results

The specimens were made from electrolytic iron prepared at Nippon Denki Seitetsu-sho and aluminium provided by Alcoc Co. The amount of aluminium contained in each alloy is shown in Table 1. The cylindrical specimen, 3 mm in diameter and 150 mm in length, was annealed for an hour at 1,000°C in the non-inductive vacuum furnace and was furnace-cooled to 700°C, and then slowly from 700°C to room temperature at the rate of 30°C per hour. This cooling rate was necessary to obtain the supperlattice of Fe_3Al. The apparatus was the same as in the preceding paper.[2] First, the specimen placed in the magnetizing coil was heated to a constant temperature, then the current was passed through it to make the circular field, and after the temperature of the specimen heated by the current through it became constant, the current was passed through the magnetizing coil to measure the effect caused by the longitudinal field, that is, the torsion of the specimen by scale and telescope.

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* The 908th report of the Reserach Institute for Iron, Steel and Other Metals. Reported in the Journal of the Japan Institute of Metals, **20** (1956), 81.

(1) H. Nagaoka and K. Honda, Phil. Mag., **4** (1902), 45.
(2) Y. Shirakawa, T. Ohara and T. Abe, Sci. Rep. RITU, A **9** (1957), 176.
(3) Y. Shirakawa, T. Ohara and T. Abe, Sci. Rep. RITU, A **9** (1957), 184.

Table 1. Maximum twisted angle (θ_m) and its corresponding longitudinal field (H_m) for various constant circular field current (H_c)

Specimen No.	Al (%)	Circular field current H_c (A) 0.5		1.0		2.0		3.0		4.0		6.0		8.0	
		θ_m (")	H_m(oe)	θ_m	H_m	θ_m	H_m	θ_m	H_m	θ_m	H_m	θ_m	H_m	θ_m	H_m
1	0	7.2	15.0	10.4	16.5	11.8	17.5	12.1	19.5	12.3	20.5	13.3	23.5	14.3	25.0
2	0.98	7.2	16.0	10.0	16.5	11.8	17.5	12.2	19.5	12.4	29.5	13.2	22.5	13.9	25.0
3	2.87	5.8	16.0	9.2	17.0	11.0	18.5	11.9	19.7	12.8	20.5	13.4	21.5	14.4	24.0
4	4.57	4.0	18.5	8.0	19.0	14.4	19.5	17.2	19.7	19.0	20.0	21.8	20.5	22.3	21.3
5	6.36	5.4	20.5	11.2	21.5	18.0	22.5	23.4	23.5	28.8	24.0	32.2	25.0	35.0	27.0
6	8.57	2.1	23.0	5.2	24.0	10.8	25.0	17.4	26.5	22.0	27.0	30.2	28.5	36.2	30.0
7	9.86	2.0	24.0	4.0	25.0	9.2	27.0	12.9	28.5	17.0	29.5	22.5	30.5	28.6	31.0
8	10.34	2.8	20.0	5.2	21.0	10.8	23.0	14.4	24.5	18.2	26.0	23.6	28.5	29.8	30.5
9	11.79	4.3	17.5	7.6	18.5	14.2	20.0	20.2	21.5	25.2	22.5	33.0	25.5	39.0	27.5
10	12.91	4.5	15.0	9.2	16.5	16.3	19.0	22.1	20.5	27.5	22.5	35.2	24.5	41.8	27.0
11	13.50	3.9	17.5	8.2	18.5	13.7	19.5	20.2	21.5	25.0	22.5	32.3	24.5	38.7	27.0
12	15.89	2.8	12.5	4.4	13.0	7.2	14.0	10.0	15.0	12.8	16.0	15.8	18.0	18.4	19.5
13	16.79	1.2	12.5	—	—	—	—	2.4	14.0	—	—	—	—	3.2	15.5

1. The effect at room temperature

The current was passed through specimen to make the circular field (H_c). The relation between the twisted angle (θ)-longitudinal field (H) curve at the constant circular field and the θ-H_c curve at the constant longitudinal field was similar to that of "Alfer".(2) For example, the results obtained with No. 8 (10.34 per cent Al) are shown in Fig. 1. As shown in the figure, the curves of torsion

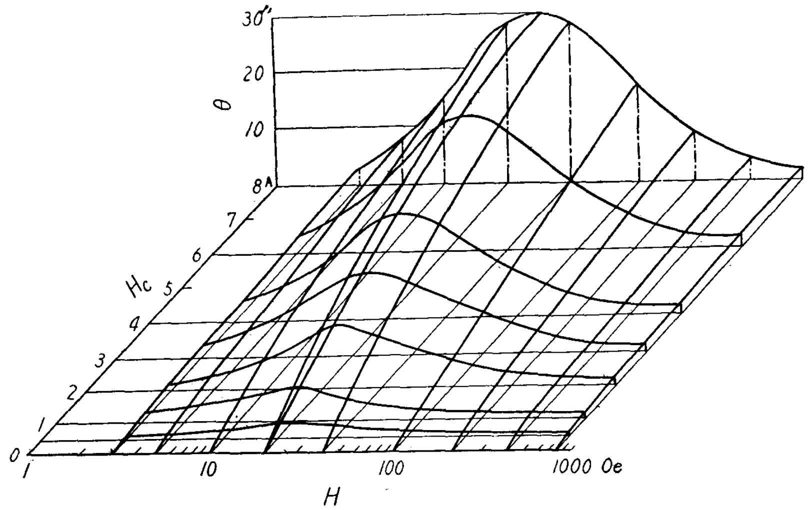

Fig. 1 Relation among the twisted angle θ, longitudinal field H and circular field current H_c at room temperature for the specimen No. 8 (10.34% Al).

are similar to one another at the constant H_c, that is as the field Hi ncreases, the torsion θ increases first slowly and then rapidly until it reaches the maximum, at which it begins to decrease; also the curves are similar to one another in the constant longitudinal magnetic field H, that is, in lower longitudinal field, θ tends to rise almost linearly and does not increase very much in the range 20~40 Oe, and in higher field it increases in proportion to the circular field.

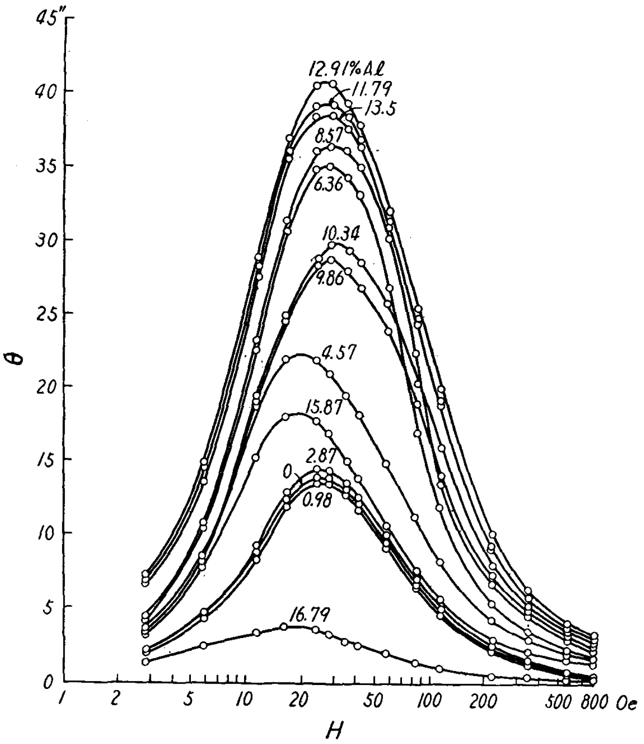

Fig. 2. Twisted angle θ-longitudinal field H curves for circular field current $H_c = 8$A at room temperature for Fe-Al alloys.

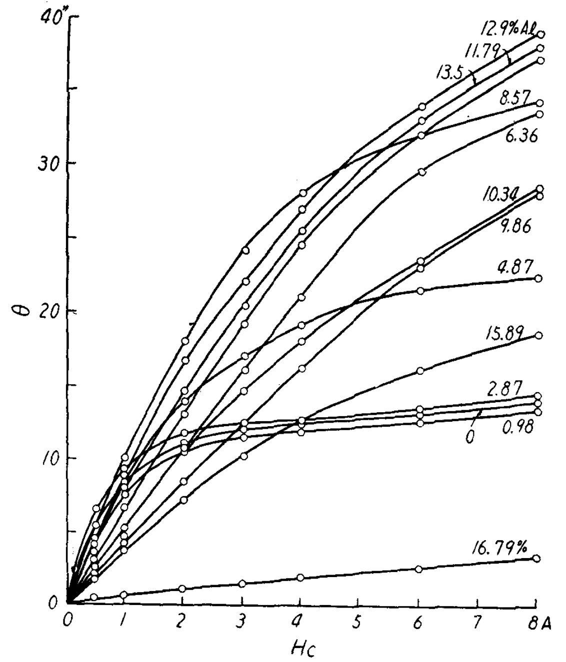

Fig. 3 Twisted angle θ-circular field current H_c curves for $H = 20$ Oe at room temperature for Fe-Al alloys.

Next, the torsion curve of each specimen at $H_c = 8$A is shown in Fig. 2, in which the number is the amount of aluminium concentration. The current density in the case of $H_c = 8$A corresponds to 1.13 A/mm^2, and the circular field is about 10.7 Oe on the surface of the specimen. The general aspect of each curve is almost similar to that of iron and the maximum value of the torsion θ_m and the corresponding field H_m do not much differ respectively from those of iron. The longitudinal magnetic field H_m showing the maximum of the torsion θ_m of each specimen is given in Table 1. As the circular field H_c increases, the torsion increases, and especially, in the specimens con taining less than 4.57 per cent Al and that containg 15.89 per cent Al, the torsion increases first rapidly and then reaches the saturation value. The maximum value of the torsion in the speci men of 16.79 per cent Al is very small and proportional to H_c. The field H_m increases almost linearly with the increase of H_c, but not severely. The relation between the maximum value of the torsion θ_m and the corresponding field H_m is almost linear except the specimens containing less than 2.87 per cent Al, in which θ_m tends to reach gradually the saturation value with the increase of H_m. Next, Fig. 3 shows the relation between the torsion θ and the circular field current at 20 Oe, which is obtained from Fig. 1. As shown in Fig. 3, in the specimen containing less than 2.87 per cent Al the torsion θ increases first rapidly and then gradually from the vicinity of 2A as H_c increases. But with the addition of Al to Fe, θ increases first in proportion to H_c and then gradually ceases to increase at some value of H_c. Especially, in the specimen of 16.79 per cent Al, θ increases linearly in proportion to H_c. The behaviours of the curves shown in Figs. 2 and 3 can also be qualitatively explained by the formula derived by Pidgeon.[4] Fig. 4 shows the relation between the torsion and aluminium concentration obtained from Fig. 3 at H_c= 8A. The specimen of 10 per cent Al is not capable of being magnetized in weak longitudinal field, and the magnetostriction alloy "Alfer" corresponds to the alloy of about 13 per cent Al.

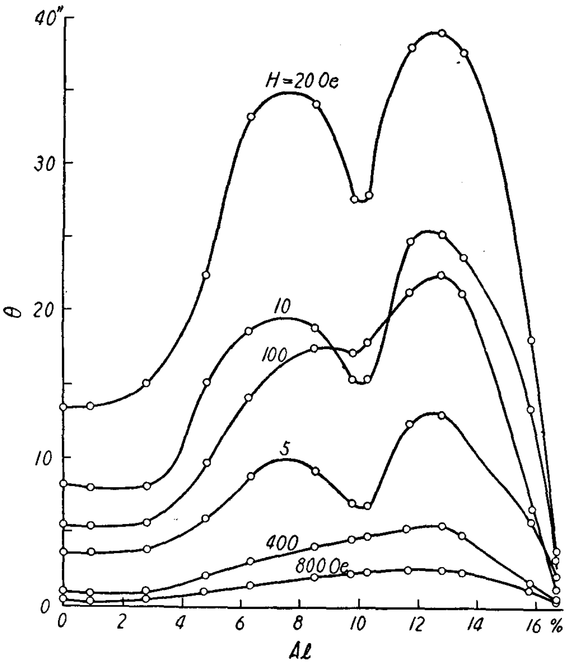

Fig. 4. Twisted angle θ-aluminium concentration curves for H_c=8A at room temperature for Fe-Al alloys.

2. The effect at high temperatures

Similar measurements were made from room temperature almost up to the magnetic transformation point at intervals of 100°C. The θ-H and θ-H_c curves obtained were almost similar respectively to those at room temperature. When H is kept constant, the relation between the torsion θ and the temperature T shows two kinds of behaviours. One is the maximum value of torsion, for example, as shown in Fig. 5 which is

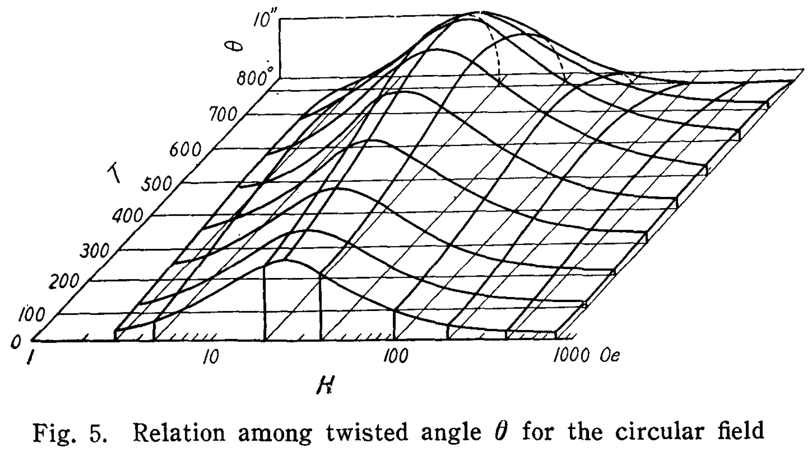

Fig. 5. Relation among twisted angle θ for the circular field current H_c of 8A longitudinal field H, and temperature T for the specimen No. 3 (2.87% Al).

the result obtained for No. 3 with the circular field current of 8A. As seen from the figure, with the rise of temperature θ increases first slowly and reaches a maximum at 500°C, at which it begins to decrease, disappearing at 750°C near the

(4) A. Pidgeon, Phys. Rev., **13** (1919), 209.

magnetic transformation point. This behaviour is also seen in specimens containing less than 4.87 per cent Al. The other, as shown in the Fig. 6, is such a behaviour that the torsion θ decreases slowly as the temperature rises, disappearing at the transformation point, which is seen in specimens containing more than 6.36 per cent Al. The results for No. 8 (10.34 per cent Al) at $H_c = 8A$ are given in Fig. 6.

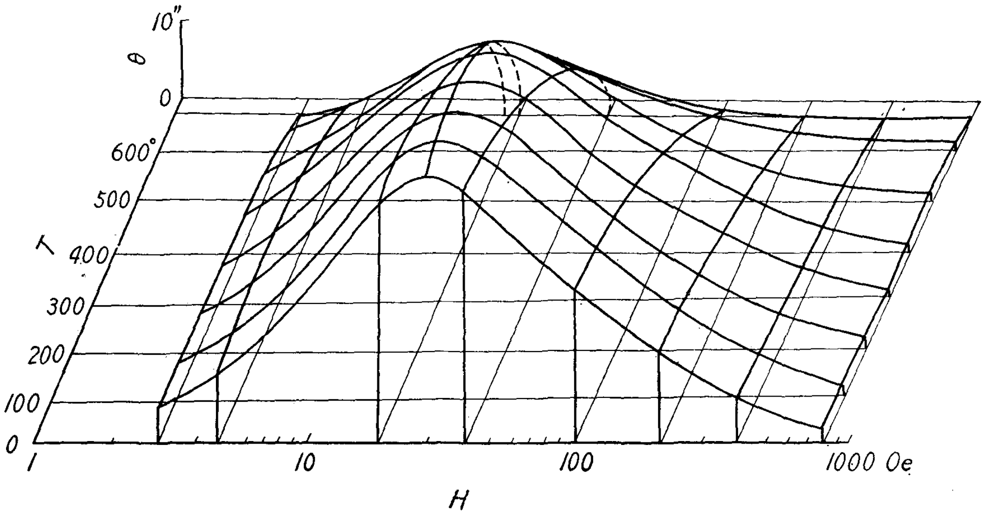

Fig. 6. Relation among the twisted angle θ for the circular field current H_c of 8A longitudinal field H, and temperature T for the specimen No. 8 (10.34% Al).

The maximum value of the torsion θ_m and the corresponding magnetic field H_m are shown in Table 2. As the temperature rises, θ_m for the specimens containing less than 4.57 per cent Al increases first slowly, and reaches a maximum, whereas in the specimens containing more than 6.31 per cent Al it decreases monotonously, disappering at the magnetic transformation point. H_m decreases as the temperature rises,

Table 2. Maximum twisted angle (θ_m) for $H_c = 8A$ and its corresponding longitudinal field (H_m) at elevated temperatures.

Specimen No.	Al (%)	Temperature (°C)															
		Room temp.		100		200		300		400		500		600		700	
		θ_m(″)	H_m(oe)	θ_m	H_m	θ_m	H_m	θ_m	H_m	θ_m	H_m	θ_m	H_m	θ_m	H_m	θ_m	H_m
1	0	14.3	25.0	14.3	25.0	14.3	25.0	17.8	23.5	19.6	23.0	22.7	22.8	23.1	22.5	17.8	20.5
2	0.98	13.9	25.0	13.9	25.0	14.6	24.5	18.2	24.5	20.0	24.0	22.8	24.0	22.5	22.5	17.1	20.0
3	2.87	14.4	24.0	14.4	23.5	16.6	22.5	18.9	22.0	20.5	21.5	22.8	21.0	21.1	20.5	16.5	19.5
4	4.57	22.5	21.5	23.5	21.0	25.3	21.0	26.2	20.5	26.4	20.5	25.2	20.0	23.3	19.5	13.2	18.5
5	6.26	35.0	27.0	34.4	27.0	33.6	27.0	32.8	26.5	31.2	26.0	26.4	24.5	22.8	19.0	8.2	18.5
6	8.57	36.2	30.0	35.6	29.0	34.6	28.5	33.0	27.5	30.8	26.0	25.6	22.5	19.2	19.5		
7	9.86	28.6	31.0	28.4	30.5	28.0	30.0	27.5	30.0	26.2	28.5	21.0	24.5	14.0	19.0		
8	10.34	29.8	30.5	29.0	28.5	27.2	27.5	25.2	25.5	23.2	25.0	18.7	22.5	11.0	19.5		
9	11.79	39.0	27.5	38.6	26.0	35.4	24.5	29.0	27.5	19.2	21.0						
10	12.91	41.8	27.0	39.0	26.0	35.2	25.0	29.3	23.5	15.6	22.5						
11	12.50	38.7	27.0	37.8	26.0	33.8	25.0	26.7	24.0	14.8	22.5						
12	15.89	18.4	19.5	15.2	18.5	7.8	17.5										
13	16.79	3.4	15.5	2.3	14.5												

The θ–T curve for each specimen is shown in Fig. 7. As already stated the behaviours of θ for the specimens containing less than 4.57 per cent Al are almost similar to those for Fe, that is, as the temperature rises θ increases first slowly and then reaches a maximum, disappearing at the magnetic transformation point. With the addition of Al to Fe, however, the maximum of θ shifts towards the side of low temperature, and it disappears at 6.36 per cent Al. θ decreases slowly as the temperature rises. The aspects of θ–T curves for the specimens containing more than 11.79 per cent Al are the same as those for "Alfer", that is, θ becomes small rapidly and then disappears at the magnetic transformation point. As a whole, the above mentioned curves are similar to the Hopkinson effect, but not explainable easily. In considering the formula derived by Pidgeon, this behaviour seems to be attributed to the

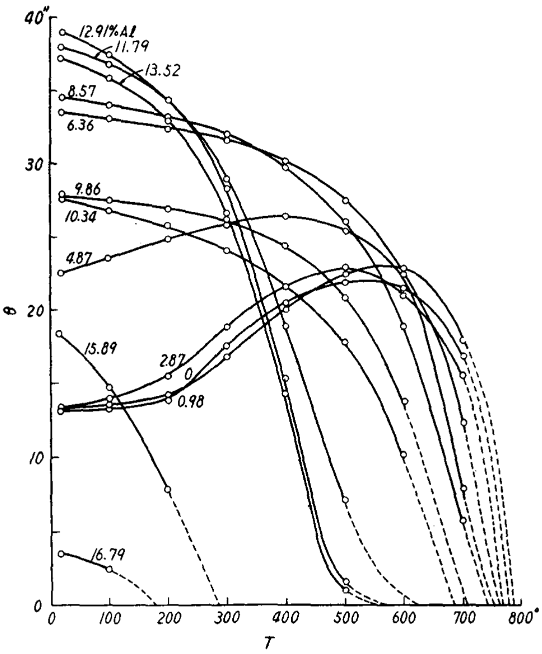

Fig. 7. Twisted angle θ-temperature T curves for H_c=8A H=20 Oe for Fe-Al Alloys.

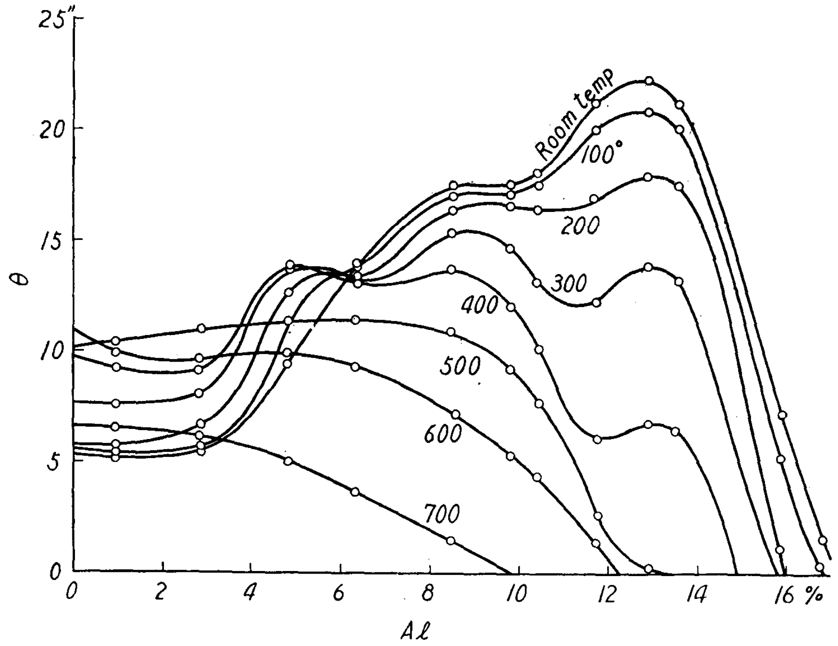

Fig. 8. Twisted angle θ-aluminium concentration curves in H_c=8A, H=100 Oe at various temperatures for Fe-Al alloys.

characteristics of magnetostriction at high temperatures. Further, the torsion vs. aluminium concentration curve at each temperature is very complicated, for example, as shown in Fig. 8, which was obtained at H_c = 8A and H = 100 Oe. In general, the curve at room temperature is similar to the magnetostriction curve and is likely to be explained qualitatively by the formula derived by Pidgeon, but the curves at high temperatures cannot be discussed well because the magnetostriction at high temperatures had not been observed. On the other hand, magnetostriction at high temperatures may be estimated from these curves.

Summary

The Wiedemann effect was measured with a series of Fe–Al alloy from room temperature almost to the magnetic transformation point, and the following results were obtained:

(1) The twisted angle θ–longitudinal field H and θ– circular field H_c curves at room temperature are similar respectively to those of Fe and "Alfer" at all aluminium concentration and each of the θ–H curve shows a maximum.

(2) Each of the θ–aluminium concentration curve at room temperature has two maxima and one minimum. This behaviour is remarkable at the field H_m showing the maximum torsion θ_m, and becomes more feeble as the field increases or decreases from the field H_m.

(3) Each of the θ-temperature curve is similar to that of Fe, when the aluminium concentration is small, while it is similar to that of Alfer when the concentration is large, that is, in the former, θ increases as the temperature rises, and after reaching a maximum it decreases rapidly, but in the latter θ decreases first slowly and then rapidly.

(4) The dependence of the θ-aluminium content curve on temperature is too complicated to understand, but, in the case of $H_c = 8$A and $H = 100$ Oe, the curve has two maxima and one minimum at room temperature, three maxima and two minima at 200∼300°C, and above 500°C the curve is very simple, showing neither maximum nor minimum.

In conclusion the present authors wish to express their hearty thanks to Dr. Hakaru Masumoto, the president, under whose kind guidance and encouragement this experiment was performed. They also thanks cordially to Mr. Yoshiyuki Sato for his co-operation to the adjustment of measuring apparatus. The present study has been supported partly by the funds of the Ministry of Education in Aid of Scientific Researches.