DISCUSSION

P. Brissonneau: It seems that you observe a temperature dependence of stabilization field more rapid than the calculated variation of $1/T$ (Fig. 3). How do you explain it?

K. Tsushima: The explanation for the result of temperature dependence of stabilization field is not given.

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

Single-Crystal Magnetostriction Measurement on Dilute Iron Alloys

R. Gersdorf, J. H. M. Stoelinga and G. W. Rathenau
Natuurkundig Laboratorium der Universiteit van Amsterdam
Amsterdam, the Netherlands

The single-crystal magnetostriction constants of iron and of dilute alloys of iron with some non-transition elements have been measured in the temperature region 4-300°K. The variations of the constants with temperature, with composition and with degree of ordering are separately discussed. Preliminary results on magnetic anisotropy are also given.

It seemed of interest to measure single-crystal magnetostriction constants[2] at low temperatures as functions of temperature in order to test the applicability of the equation of Kittel and van Vleck[1] to metals and alloys.

It also seemed worthwhile to investigate the specific influence of non-transition elements added as dilute solutes to iron. It is well known that silicon and aluminum in additions up to about 10 atomic % act as simple diluents of iron when judged from the saturation change. Similar behaviour is found for the alloys of iron with other non-transition elements, which we have measured (Sn, see reference 2). Part of this program has already been carried out by others[3][4][5][6].

Experimental and results

The iron crystal was produced from Ferrovac E iron (impurities about 0.05 at %, except O, C, N, of which C and N had been removed). The alloy crystals have also been prepared from Ferrovac E or purer iron and high-purity solute elements. The crystals were homogenized. No inhomogeneities were revealed by micrographic inspection. Since no single crystal of an Sn-Fe alloy has been obtained, the measurements in this case were done on a polycrystalline specimen with a strong texture.

Magnetostriction was measured at 10000 and 20000 Oe by the strain-gauge method[7]. The necessary corrections have been taken into account[7]. h_0' has been measured isothermally. In order to determine the magnetic anisotropy, torques were measured with strain gauges. The results on K_1 are preliminary. They have an accuracy of about 5%.

Table I represents h_1, h_2, h_0', K_1 and M_s. The measurements at 77° and 293° K are given together with the values of other authors in Figs. 1, 2, 3, 4. The symbols used are defined in reference 2.

Discussion

The measurements, though far from being

explicable, given rise to the following remarks.

1) The change of h_1 with temperature, $\Delta h_1=(dh_1/dT)/\Delta T$, is a slowly varying function of composition even when h_1 itself varies rapidly. This is demonstrated by the 10.6 at. % Si-alloy in the ordered, and disordered states. A temperature decrease from 293 to 77°K leads to approximately the same Δh_1 for both alloys. It causes a sign reversal of h_1 for the ordered alloy only. Such behaviour could be expected if two large terms of opposite sign and different temperature dependence would both contribute to h_1, almost compensating each other.

The temperature variation of h_2 is great-

Table I.

	T (°K)	h_1 ($\times 10^{-6}$)	h_2 ($\times 10^{-6}$)	h_0' ($\times 10^{-10}$ O_e^{-1})	K_1 ($\times 10^3$ $joule/m^3$)	M_s ($\times 10^6$ A/m)	
iron	4	35 *	—45	~2.0		1.76	(ref. 2+10)
	77	35.0*	—44.8	1.6	49	1.76	
	190	35.5*	—39.9	1.7	—	1.74	
	293	36.2*	—34.0	1.8	46	1.72	
Fe+3.9 wt% Si	4	23.6	—3.1	—	—	1.61	(ref. 2+10)
(7.4 at%)	77	24.1	—3.2	3.3	40	1.61	
	190	30.0	—3.8	3.0	—	1.59	
	293	37.0	—4.2	2.9	34	1.56	
Fe+5.6 wt% Si	4	—12	3.5	—	—	1.52	(ref. 2+10)
(10.6 at%)	77	—10	3.5	3.6	—	1.52	
more ordered	200	—0.5	2.5	3.5	—	1.50	
	293	9.8	2.4	2.8	—	1.48	
idem	77	2.6	2.7	3.1	—	1.52	(ref. 2+10)
more disordered	293	18.2	2.4	3.0	—	1.48	
Fe+4.6 wt% Al	4	48	—30	—	—	—	
(9.1 at%)	77	51.5	—28.5	4.1	51	1.53	
	293	60	—21.3	2.8	45	1.49	
Fe+8.6 wt% Al	77	127.5	—11.7	4.6	32	—	(ref 2)
(16.3 at%)	293	138	—9.6	3.5	25	1.34	
Fe+0.52 wt% Be	4	38.5	—50	—	—	—	
(3.1 at%)	77	39.5	—50	3.2	62	1.70	
+0.13 at% Al	293	52.5	—34.3	2.2	51	1.64	
Fe+1.16 wt% Be	77	94.5	—49	3.2	72	1.65	
(6.8 at%)	293	99	—34	1.6	48	1.60	
+0.4 at% Al							
Fe+5.3 wt% Ge	77	32.5	—30	3.1	53	1.69	
(4.2 at%)	293	38.5	—21.5	2.3	48	1.64	
Fe+2.0 wt% Sn	77	~28	~—41	2.2	—	—	(ref 2)
(1.0 at%)	293	~31	~—29	1.6	—	~1.70	
error	—	±0.2 or 3% (unless error in h_4)	±0.2 or 3%	±0.3 at293°K, ±1.0 at 77°K	5%	—	

* h_1+h_4 instead of h_1. ($h_4=(2\pm3)\times10^{-6}$)

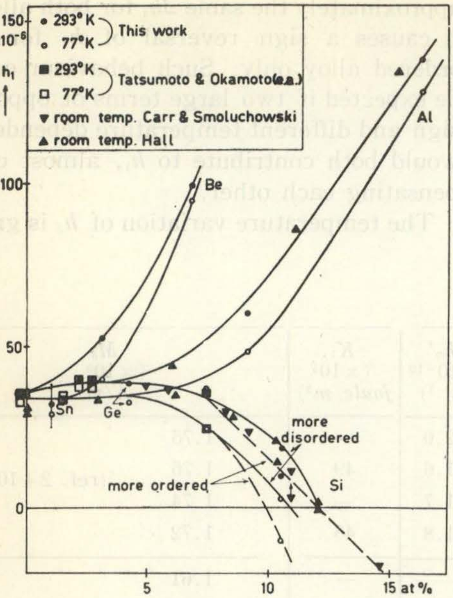

Fig. 1

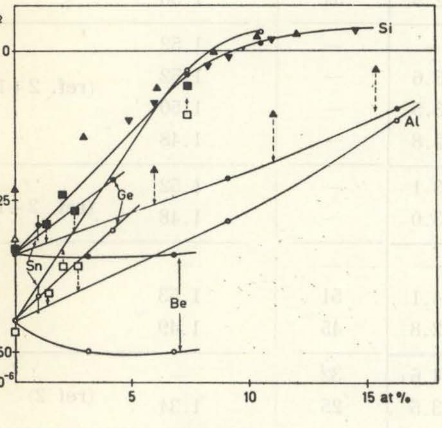

Fig. 2.

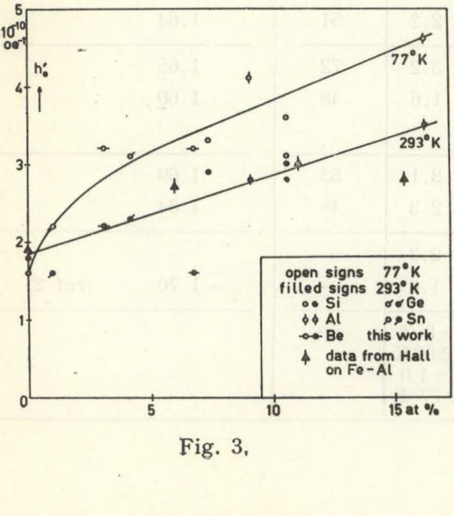

Fig. 3,

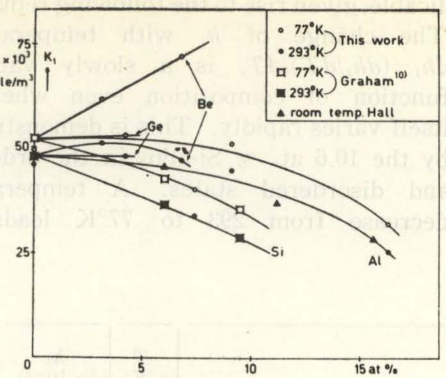

Fig. 4.

ly different from that of h_1. It seems to be roughly proportional to the value of h_2.

Assuming a decrease of the elastic moduli of about 6% in the temperature interval 4-300°K, which is reasonable for these materials[8) 9)], the observed temperature variation of both h_1 and h_2 often turns out to be much larger than predicted by the theory of Kittel and van Vleck. Moreover, the magnetoelastic coupling constant B_1, often increases with temperature.

2) h_1 and h_2 also depend differently on concentration. For the Al- and Si-alloys, at least, h_2 changes about linearly with concentration but h_1 changes at a higher power in this temperature region.

The influence of the additional elements for both h_1 and h_2 has been shown to change in the order of succession: Be, Al, Ge, Si, whereas Sn is near to Ge and Si. This suggests a relation to the valencies of the added elements. The atomic diameter does not seem to be decisive since that of Be and Si is small while that of Al and Sn large in these alloys.

3) Atomic ordering of the Fe-Si alloys has a small effect on h_2, but a rather large one on h_1. It must be kept in mind that in the samples of figure 1 only a small difference of order has been obtained and this in only a limited region of concentrations. The relative change of dimensions with ordering is only 4.10^{-4} for our 10.6 at % Si-Fe sample (several hours furnace cooling from 800°C, versus quenching in Silicon oil). The large influence of order solely upon h_1 can be related as follows

with the other observations. h_2 depends linearly, but h_1 varies with concentration at a higher power. It seems reasonable that the latter is due to radical changes if an iron atom has more than one non-iron neighbour. On ordering (Fe_3Si-type), the Fe atoms can be distinguished in different sublattices. On some sublattices they have no Si-neighbours while on the others they have many. This holds true for nearest and next nearest neighbours.

4) The forced magnetostriction (volume magnetostriction) h_0', does not go to zero at low temperatures, it does, within the experimental error, not change below room temperature. We think this means that h_0' is due to a real increase of the atomic magnetic moment with increasing field. Fig. 3 also shows that h_0' does not depend on the kind of element added within the experimental error.
5) In figure 4 for the magneto-crystalline anisotropy, the relatively large temperature dependence of the Be-alloys is remarkable. The order of succession for the different elements added is similar to that found for h_1 and h_2.

The work has been supported by the foundations F.O.M. and Z.W.O.

References

1 C. Kittel and J. H. van Vleck: Phys. Rev. **118** (1960) 1231.
2 R. M. Bozorth: Ferromagnetism, 1953.
3 E. Tatsumoto and T. Okamoto: J. phys. Soc. Japan **14** (1959) 1588; E. Tatsumoto, K. Kuwahara, H. Kimura, T. Okamoto: J. Sci. Hiroshima Univ. A **24** (1960) 367.
4 D. A. Shturkin: Doklady Acad. Nauk SSSR **58** (1947) 581.
5 W. J. Carr, Jr. and R. Smoluchowski: Phys. Rev. **83** (1951) 1236.
6 R. C. Hall: J. Appl. Phys. **30** (1959) 816.
7 R. Gersdorf, forthcoming thesis Amsterdam, (1961); R. Gersdorf: Physica **26** (1960) 553; R. Gersdorf, J. H. M. Stoelinga, G. W. Rathenau: Physica **27** (1961) 381.
8 J. A. Rayne and B. S. Chandrasekhar: Phys. Rev. **122** (1961) 1714.
9 Prof. C. S. Smith (Cleveland), private communication.
10 C. D. Graham: J. Appl. Phys. **31** (1960) 150S.

DISCUSSION

E. TATSUMOTO: Did not you have any trouble for cementing the strain gauge on the sample at low temperature?

G.W. RATHENAU: Yes. But the difficulty was avoided by refining the cementing technique. After taking low temperature values generally room temperature measurements were done again to make sure that the original bond between specimen and gauge had not changed.