

Citation:

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Physics. — “*The magneto-optic KERR-effect in ferromagnetic compounds and metals.*” III. By PIERRE MARTIN of Geneva. (Communication from the BOSSCHA-Laboratory). (Communicated by Prof. H. DU Bois).

The purpose of the following work was the extension of the investigations of LORIA¹⁾ on the magneto-optical properties of the newly obtained ferromagnetic compounds and alloys. I limited myself to the determination of the dispersion of different manganese and iron compounds, and to a repetition of the measurements for the case of the three chief metals. The literature has been fully discussed by LORIA so that it is not necessary to introduce it here; his experimental arrangement has been again adopted, for a description of which I may therefore refer to his publication. The direct vision monochromator, with high illuminating power, was subjected to a new calibration. Throughout, pole end-pieces (V) with rectangular bore were used, the profile of which ($2,5 \times 4$ mm.) was nearly always exceeded by the size of the mirrors: the latter were irregularly shaped and fixed by means of plaster of Paris.

As a simple relation between the optical constants and the dispersion curve was sought for in vain by LORIA, I have not on this occasion determined the former. In general, for my specimens the extinction was good and consequently the ellipticity only very slight; considering the very small rotations in most cases, its determination appeared as yet scarcely possible of execution although certainly to be desired.

MATERIALS INVESTIGATED.

Manganese compounds. “Mn 65, Sn 35” = Mn₃Sn, and “Mn 35, Sb 65” = Mn Sb nearly, were very kindly given to me for investigation by Prof. TAMMANN. The relations between the amounts of the metals combined together correspond, according to HONDA, to the most ferromagnetic compound or alloy respectively²⁾. Besides these, I investigated a specimen of Mn Sb and Mn B from Prof. WEDEKIND and also Mn Bi from Dr. HILPERT. The metal manganese was found inactive by LORIA.

Iron compounds. A piece of a carbon alloy consisting substantially of cementite (Fe, C) was kindly prepared for me by Dr. HILPERT. For normal pyrrhotine (Fe, S₂) I am indebted to Prof. P. WEISS of Zürich. In addition to these compact magnetic pyrite and amorphous

¹⁾ STANISLAW LORIA. These Proceedings Vol. 12, p. 895 and Vol. 14, p. 970.

²⁾ KÔTARÔ HONDA. Ann. der Phys. 32, p. 1003, 1910.

iron sulphide from the laboratory collection were investigated. A piece of cerium-iron was also subjected to observation.

Metals. For electrolytic iron and also for pure cobalt and nickel I am again indebted to Prof. WEISS¹⁾, who has investigated their saturation values of magnetisation.

The dispersion of the KERR-effect in the metals has been moreover previously determined by DU BOIS²⁾.

I beg here to express my best thanks to those gentlemen who have assisted me by supplying the materials.

In the following tables are given: λ , the wave-length of the observed light in $\mu\mu$. Δ , the double rotation as observed in mm. on the scale after reversal of the current. ϵ , the simple rotation in minutes, $\pm\sigma\epsilon$, the mean error in minutes and percent respectively. N the number of readings taken for each direction of the current.

MANGANESE COMPOUNDS.

*Manganese boride*³⁾ (Mn B). In this case, my attempts to observe any rotation gave but negative results. Although the material was porous and on that account the mirror not very bright I was able to convince myself that if a rotation existed it was less than 0,3'.

Manganese-tin. (Mn 65, Sn 35 = Mn₄Sn). The dispersion curve here remains entirely in the region of negative values (Fig. 1). The

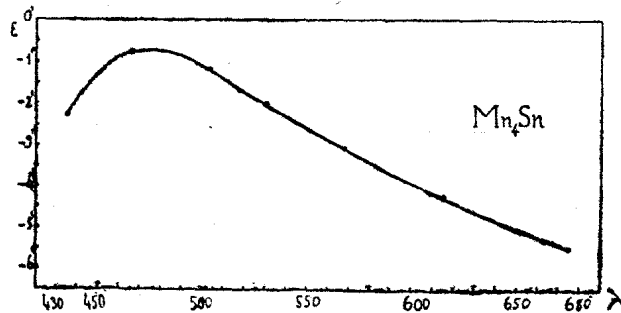


Fig. 1.

curve, which in the violet falls rather steeply, reaches a numerical minimum in the blue and then gradually rises again. The rotation always remains of a small order as one would expect from considering the small magnetisability of the material.

Two mirrors on the same piece, obtained by grinding at right angles to one another, gave results in good agreement as is shown by tables 1 and 2.

¹⁾ P. WEISS, Journ. de Physique (4), 9, p. 373, 1910.

²⁾ H. DU BOIS, Wied. Ann. 39, p. 25, 1890. Phil. Mag. (5) 29 p. 253, 1890.

³⁾ E. WEDEKIND, Zeitschr. für Physik. Chemie 66, p. 614, 1909.

TABLE 1.

$\varepsilon = f(\lambda)$		Mn_4Sn (saturated)		TAMMANN
N	λ (μ)	Δ (mm)	ε (min.)	$\pm \delta\varepsilon$
20	435	-14,8	-2,24'	0,07' = 3,1 ‰
20	466	-5,0	-0,75	0,03 = 4 "
20	503	-7,9	-1,18	0,02 = 1,4 "
20	567	-20,2	-3,03	0,02 = 0,7 "
20	615	-28,4	-4,26	0,02 = 0,5 "
20	675	-36,8	-5,52	0,13 = 0,25 "

TABLE 2.

$\varepsilon = f(\lambda)$		Mn_4Sn (saturated)		TAMMANN
N	λ (μ)	Δ (mm)	ε (min.)	$\pm \delta\varepsilon$
15	466	-5,0	-0,75'	0,05' = 6,7 ‰
15	530	-13,3	-2,00	0,03 = 1,3 "
12	567	-20,0	-3,00	0,04 = 1,3 "
15	615	-28,4	-4,26	0,04 = 1 "

Manganese-antimonide (Mn 35, Sb 65 = Mn Sb nearly). The material of Prof. TAMMANN showed a strong negative rotation which reached its

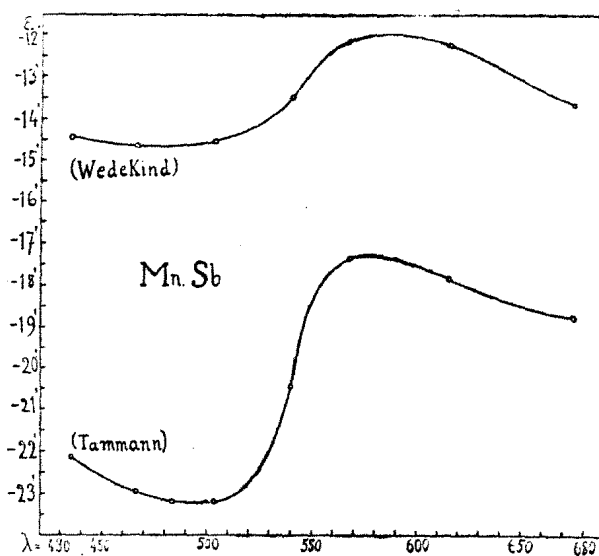


Fig. 2.

numerically highest point in the blue-green and then fell steeply in the green passing through a minimum at about $580 \mu\mu$; it then slowly increased again as it approached the red (Fig. 2).

T A B L E 3.

$\epsilon = f(\lambda)$ *MnSb* (saturated) TAMMANN

<i>N</i>	λ ($\mu\mu$)	l (mm)	ϵ (min.)	$\pm \partial\epsilon$
40	435	-148,9	-22,35'	0,15' = 0,75%
35	466	-153,5	-23,02	0,06 = 0,25 "
25	483	-154,7	-23,21	0,04 = 0,17 "
25	503	-154,6	-23,19	0,03 = 0,13 "
40	530	-136,4	-20,46	0,03 = 0,15 "
27	567	-115,7	-17,36	0,01 = 0,06 "
25	615	-119,0	-17,86	0,02 = 0,11 "
35	675	-125,0	-18,75	0,02 = 0,11 "

A second specimen of MnSb coming from Prof. WEDEKIND gave a similar dispersion curve agreeing in character with the above. The rotation however always remained smaller than in the case of the first specimen. It can therefore probably be assumed that this corresponds better to the ferromagnetically best compound MnSb, whose existence has lately been established with great probability by HILPERT and DIECKMANN¹⁾.

T A B L E 4.

$\epsilon = f(\lambda)$ *MnSb* (saturated) WEDEKIND

<i>N</i>	λ ($\mu\mu$)	Δ (mm)	ϵ (min.)	$\pm \partial\epsilon$
30	435	-96,1	-14,41'	0,16' = 1,1%
25	466	-97,1	-14,57	0,09 = 0,6 "
20	503	-97,0	-14,55	0,05 = 0,3 "
21	530	-91,0	-13,53	0,03 = 0,2 "
20	567	-80,9	-12,14	0,01 = 0,1 "
20	615	-81,7	-12,25	0,02 = 0,2 "
21	675	-87,5	-13,14	0,05 = 0,4 "

¹⁾ Cf. KŌTARŌ HONDA loc. cit. E. WEDEKIND, Chem. Ber. 40 p. 1266, 1907
S. HILPERT and TH. DIECKMANN, Chem. Ber. 44 p. 2833, 1911.

*Manganese-bismuthide*¹⁾ (MnBi). The rotation, which was negative at both ends of the spectrum (Fig 3), reached a positive maximum at 530 $\mu\mu$. Points of inversion were found at 468 $\mu\mu$ and 617 $\mu\mu$. Although the mirror was not very bright I was yet able to measure the rotation fairly accurately in spite of its small amount.

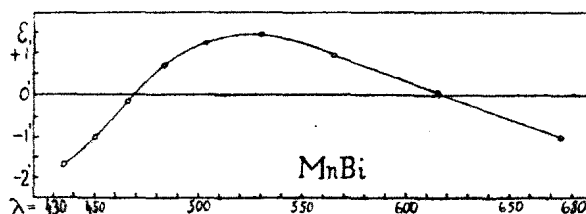


Fig. 3.

TABLE 5.

$\epsilon = f(\lambda)$		<i>Mn Bi</i> (saturated)		HILPERT
<i>N</i>	λ ($\mu\mu$)	L (mm)	ϵ (min.)	$\pm \delta\epsilon$
25	435	- 11,0	- 1,65'	0,13' = 7,7 $\frac{0}{10}$
25	450	- 6,7	- 1,00	0,07 = 7,3 »
50	466	- 1,1	- 0,16	0,04 = 22,0 »
25	483	+ 4,8	+ 0,72	0,05 = 6,5 »
21	503	+ 8,4	+ 1,26	0,03 = 2 »
21	530	+ 9,9	+ 1,48	0,03 = 2 »
21	567	+ 6,3	+ 0,94	0,03 = 2,8 »
70	615	+ 0,3	+ 0,045	0,015 = 33,3 »
30	675	- 6,6	- 0,99	0,02 = 2 »

IRON COMPOUNDS.

Iron carbide (Fe_3C , Cementite). As the material contained for the most part cementite in needle-like crystalline layers mixed with other substances, the mirror was treated with sulphurous acid so that the cementite surfaces did not change their reflecting power while the other constituents were strongly darkened. Measurements carried out on six different parts of the surface yielded somewhat different results. All the curves however show a certain similarity viz. a very

¹⁾ S. HILPERT and TH. DIECKMANN, Chem. Ber. 44 p. 2331, 1911. E. WEDEKIND and A. VEIT, Chem. Ber. 44 p. 2665, 1911.

strong negative rotation having a numerical maximum in the violet and indicating a decrease towards the ultra-violet. It falls steeply in the blue region until the green or yellow-green is reached and then increases again towards the red. The carbon atom of the carbide accordingly produces a considerable change in the dispersion curve, compared with that of pure iron (table 12). Four of the curves are represented in fig. 4 and tab. 6 to 9. The two other places gave a smaller rotation. A consideration of the etched figures on the surface show that a better agreement for such a complicated structure can hardly be expected. On this account the investigation of alloys appears altogether more difficult than in the case of well defined compounds.

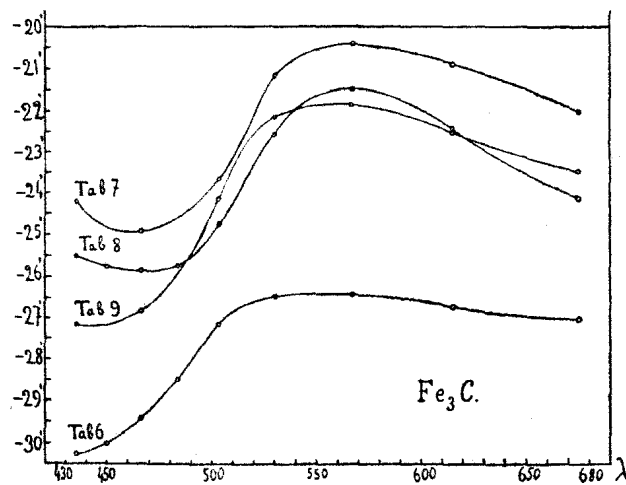


Fig. 4.

TABLE 6.

$\epsilon = f(\lambda)$		Iron carbide (saturated)		HILPERT
N	$\lambda (\mu\mu)$	Δ (mm)	ϵ (min.)	$\pm \delta z$
30	435	-201,9	-30,28'	0,05' = 0,17%
25	450	-200,0	-30,00	0,03 = 0,10 „
20	466	-196,3	-29,42	0,02 = 0,07 „
20	483	-189,8	-28,48	0,02 = 0,07 „
20	503	-180,8	-27,13	0,02 = 0,07 „
20	530	-176,3	-26,45	0,01 = 0,04 „
20	567	-176,0	-26,40	0,02 = 0,08 „
20	615	-177,7	-26,66	0,01 = 0,04 „
20	675	-180,1	-27,01	0,03 = 0,11 „

TABLE 7.

N	$\lambda (\mu\mu)$	L (mm)	ε (min.)	$\pm \delta\varepsilon$
25	435	-161,4	-24,20	0,10' = 0,40'₀
25	466	-166,1	-24,91	0,05 = 0,2 "
20	503	-157,8	-23,66	0,07 = 0,3 "
20	530	-141,1	-21,17	0,05 = 0,2 "
20	567	-136,0	-20,40	0,02 = 0,1 "
20	615	-139,6	-20,91	0,02 = 0,1 "
20	675	-146,8	-22,02	0,04 = 0,2 "

TABLE 8.

N	$\lambda (\mu\mu)$	L (mm)	ε (min.)	$\pm \delta\varepsilon$
25	435	-170,0	-25,50'	0,05' = 0,20'₀
25	450	-171,7	-25,75	0,03 = 0,1 "
20	466	-172,1	-25,81	0,03 = 0,1 "
20	483	-171,7	-25,75	0,03 = 0,1 "
20	503	-165,0	-24,76	0,03 = 0,1 "
20	530	-150,3	-22,55	0,02 = 0,1 "
20	567	-143,1	-21,46	0,02 = 0,1 "
20	615	-149,4	-22,40	0,03 = 0,1 "
20	675	-161,0	-24,14	0,03 = 0,1 "

TABLE 9.

N	$\lambda (\mu\mu)$	L (mm)	ε (min.)	$\pm \delta\varepsilon$
30	435	-181,0	-27,15'	0,07' = 0,3 %₀
25	466	-178,7	-26,79	0,03 = 0,2 "
30	503	-161,0	-24,14	0,04 = 0,1 "
25	530	-147,5	-22,13	0,01 = 0,04 "
25	567	-145,4	-21,81	0,01 = 0,05 "
20	615	-150,0	-22,50	0,01 = 0,04 "
20	675	-156,3	-23,44	0,03 = 0,1 "

Normal Pyrrhotine ($\text{Fe}_7\text{S}_8 = (\text{FeS})_6 \text{Fe}_2\text{S}_2$, from Morro Velho, Brazil). The piece with which I made my measurements was polished, in the first case, parallel to the magnetic plane and in the second case in a plane normal to this and to the direction of easiest magnetisation ¹⁾. The first mirror, as was to be expected, showed no rotation whatsoever. On the second surface however a positive rotation of the order of one minute was to be observed for the whole region of the spectrum. Even at the ends of the spectrum no indication of an inflection in the dispersion curve could be found: (perhaps a trace of an increase in the violet). I repeated the same measurements thereupon more accurately, the slit of the monochromator being widened, using a brighter yellow and blue illumination. The field here amounted to at least 12 kgs.

T A B L E 10.

$\epsilon = f(\lambda)$		<i>Normal Pyrrhotine</i> (saturated)		WEISS
N	λ (μ)	L (mm)	(min.)	$\pm \epsilon^2$
35	435	+ 6,6	+ 0,98'	0,04' = 4 $\frac{1}{10}$
30	»	+ 6,7	+ 1,00	0,05 = 5 »
25	466	+ 6,3	+ 0,94	0,04 = 4 »
20	483	+ 6,6	+ 0,97	0,04 = 4 »
20	503	+ 6,4	+ 0,95	0,03 = 3 »
20	530	+ 6,5	+ 0,96	0,03 = 3 »
20	567	+ 6,4	+ 0,95	0,02 = 2 »
20	615	+ 6,6	+ 0,97	0,03 = 3 »
25	675	+ 6,3	+ 0,94	0,04 = 4 »
30	»	+ 6,6	+ 0,97	0,03 = 3 »
20	blau	+ 6,4	+ 0,94	0,02 = 2 »
20	»	+ 6,6	+ 0,96	0,01 = 1 »
20	gelb	+ 6,4	+ 0,95	0,02 = 2 »
20	»	+ 6,5	+ 0,96	0,01 = 1 »

Compact magnetic pyrite (presumably from Obermais, Tyrol). A naturally reflecting surface was previously found by du Bois to show

¹⁾ According to the above formula this substance ought to be regarded as Sulphopentaferroferrite. P. Weiss, Journ. de Phys. (4) 4 p. 469, 1905 finds for the saturation value of magnetisation about 60 to 75 C.G.S.

no effect; this was irregular and moreover parallel to the magnetic plane. In the present work, as in the case of pyrrhotine, a mirror was obtained by grinding, normal to the above. It gave a small positive rotation of some tenths of a minute.

Amorphous iron sulphide (Fe S). This substance, which is not ferromagnetic, was also investigated by du Bois l. c. in 1889. The same mirror now also gave a negative result. Should a rotation exist, it must be smaller than 0,3'.

Cerium-iron. The dispersion in the case of pyrophorous cerium-iron of unknown composition exhibited nothing exceptional. The rotation increased a little on passing from violet to red. The material was not quite saturated.

TABLE 11.

 $\varepsilon = f(\lambda)$ *Cerium-iron* (nearly saturated)

N	λ ($\mu\mu$)	Δ (mm)	ε (min.)	$\pm \delta\varepsilon$
25	435	-33,9	-5,09'	0,05' = 1 ‰
20	466	-36,7	-5,50	0,04 = 0,7 „
20	503	-39,8	-5,97	0,02 = 0,3 „
20	530	-41,5	-6,22	0,01 = 0,2 „
20	567	-42,7	-6,41	0,01 = 0,2 „
20	615	-43,5	-6,52	0,02 = 0,3 „
25	675	-44,0	-6,60	0,03 = 0,4 „

TABLE 12.

 $\varepsilon = f(\lambda)$ *Iron* (unsaturated) WEISS

N	λ ($\mu\mu$)	Δ (mm)	ε (min.)	$\pm \delta\varepsilon$
25	435	-126,4	-18,96'	0,10' = 0,5 ‰
20	483	-131,0	-19,65	0,05 = 0,25 „
20	530	-136,6	-20,47	0,03 = 0,15 „
20	567	-141,7	-21,25	0,02 = 0,09 „
20	615	-149,5	-22,42	0,02 = 0,09 „
20	675	-164,6	-24,70	0,03 = 0,12 „

METALS.

Iron (electrolytic). The dispersion curve remains throughout in the negative region, numerically increasing from violet to red with an indication of a minimum in the ultraviolet. The iron investigated by DU Bois, loc. cit., showed a dispersion of a similar but more marked character. The material was not saturated.

Cobalt. The curve showed a flat numerical minimum in the blue-green near 530 $\mu\mu$. Otherwise there is nothing particular to be noticed. In the case of the impure cobalt investigated by DU Bois the minimum was even less marked.

TABLE 13.

$\epsilon = f(\lambda)$		<i>Cobalt</i> (unsaturated)		WEISS
N	$\lambda(\mu\mu)$	Δ (mm)	ϵ (min.)	$\pm \delta\epsilon$
25	435	-141,7	-21,25'	0,12' = 0,560%
20	483	-134,6	-20,20	0,05 = 0,25 "
20	530	-131,5	-19,74	0,02 = 0,10 "
20	567	-132,8	-19,92	0,01 = 0,05 "
20	615	-135,3	-20,28	0,01 = 0,05 "
20	675	-141,0	-21,15	0,03 = 0,14 "

Nickel. The curve showed a minimum in the yellow but otherwise no singularities. The dispersion of the original nickel-mirror of DU Bois was exactly proportional to this. The metal was not completely saturated.

TABLE 14.

$\epsilon = f(\lambda)$		<i>Nickel</i> (nearly saturated)		WEISS
N	$\lambda(\mu\mu)$	L (mm)	ϵ (min.)	$\pm \delta\epsilon$
20	435	-57,6	-8,64'	0,05' = 0,560%
20	483	-56,0	-8,39	0,02 = 0,24 "
20	530	-54,3	-8,15	0,01 = 0,12 "
20	567	-53,3	-8,00	0,01 = 0,12 "
20	615	-55,5	-8,32	0,01 = 0,11 "
20	675	-59,7	-8,96	0,02 = 0,22 "