Physics. — *The influence of magnetic fields on supraconductors.* By W. J. DE HAAS and J. VOOGD. (Comm. N⁰. 208*b* from the Physical Laboratory at Leiden.)

§ 1. In a preceding paper we discussed the magnetic disturbance of the supraconductivity of some alloys [1]).

For all investigated alloys the magnetic threshold value was found to rise more rapidly with lowering of the temperature than for pure metals.

In order to investigate whether this is a general property of supraconductive alloys, an extension of the data was very desirable.

The investigation namely had been made with the combination. Bi_5Tl_3 only and quantitavely with the combination Sb_2Tl_7 and for the solid solutions of cadmium in tin and of bismuth in tin.

So we now wished to determine for other alloys also the magnetic threshold value at different temperatures. This question is of importance not only for the special problem of supraconductivity, but also for an other purpose.

Nowadays we know, that with a solenoid of supraconductive material magnetic fields can be generated without development of heat, if only the excited magnetic fields are below the threshold value of the supraconductor.

If therefore this magnetic threshold value lies very high, the generated magnetic fields can also reach a very high value.

In connexion with the high transition point of lead we planned to make an investigation of lead alloys. In this paper we will give the results of the investigation of the combination $PbTl_2$ and Sb_2Sn_3, of alloys lead-bismuth, of an alloy lead-tin-bismuth and of an alloy lead-tin-bismuth-cadmium.

§ 2. *The combination $PbTl_2$.*

For this research we used the rod, of which we had already determined the transition point (in collaboration with Prof. v. AUBEL) [1]).

The magnetic field was generated by a solenoid placed round the helium cryostat and parallel with the axis of the rod. This solenoid cannot give fields above 1000 gauss.

As the magnetic threshold value rapidly increased with fall of temperature, the measurements had to be made immediately below the transition point.

The results are given in table 1 and in fig. 1.

It is striking, that the magnetic field interval, in which the resistance

1) Comm. Leiden N⁰. 208*a*.
These Proc. Vol. 33, 1930, p. 258.

comes back is much greater than in the case of a longitudinal disturbance of the supraconductivity of pure metals.

TABLE 1. *Pb Tl$_2$*.

H	R		T	P_{helium} in m.m.
21.4 gauss	0	Ω	4.05	647
33.6	0.000015			
35.5	0.000064			
37.5	0.000136			
41.3	0.000397			
45.8	0.000682			
55.6	0.000917			
101.9	0.000917			
42.8	0.000464			
0	0			
132.5	0.000106		3.97	597
135.0	0.000242			
139.1	0.000455			
143.4	0.000659			
147.7	0.000815			
151.9	0.000882			
171.2	0.000926			
214.0	0.000926			
321.0	0.000926			
139.1	0.000478			
0	0			
139.1	0.000478			
214.0	0		3.90	557
237.5	0.000282			
241.8	0.000464			
246.1	0.000646			
252.5	0.000822			
258.9	0.000901			
267.5	0.000915			
278.2	0.000924			
321.0	0.000926			
255.5	0.000880			

Further on we shall see, that this is also the case with the combination Sb_2Sn_3.

For both combinations the hysteresis phenomenon could not be proved. From the above we expect that with respect to the form of the mag-
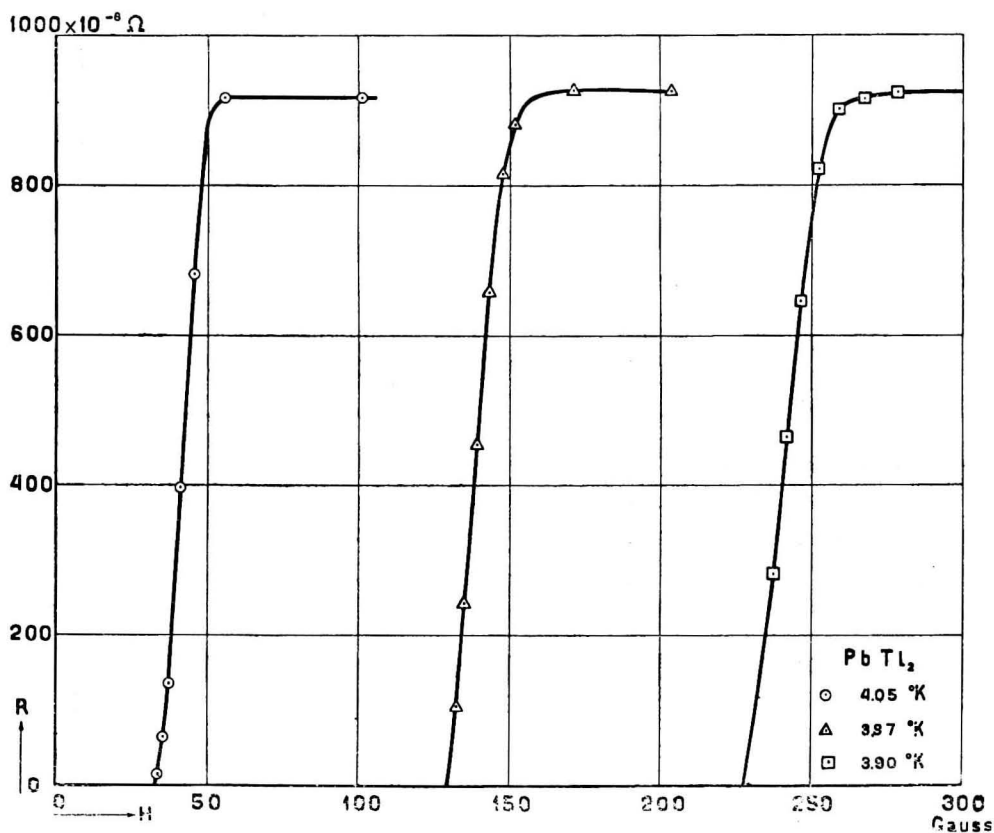

Fig. 1.

netic transition curve also characteristic differences exist between alloys and pure metals.

It may however be that inhomogeneities in the investigated rods are the cause of these differences. We intend to investigate these problems with more refined means.

For the different temperatures we give in table 2 the value of the mag-

TABLE 2. *Pb Tl₂*.

T	$H(w^{1}/_{2})$
4.05 °K.	42 gauss
3.97	139
3.90	242

netic field for which the resistance is reduced to half of its normal value $(H_{(w\,1/2)})$.

§ 3. *The combination Sb_2Sn_3.*

We used the rod, the transition point of which had been determined by Prof. V. AUBEL [1]. In table 3 and in fig. 2 the magnetic disturbance for different temperatures has been given, while the value $H_{w\,1/2}$ for these temperatures is to be found in table 4.

The difference with the pure metals, though much less pronounced than for the combination $PbTl_2$, is also found to exist here.

TABLE 3. Sb_2Sn_3.

H	R	T	p_{helium} in m.m.
42.8 gauss	0.000020 Ω	3.79	5.01
51.4	0.000066		
57.8	0.000121		
70.6	0.000256		
81.3	0.000352		
96.3	0.000439		
139.1	0.000442		
74.9	0.000295		
70.6	0.000256		
83.9	0.000082	3.69	449
96.3	0.000194		
107.0	0.000287		
149.8	0.000441		
96.3	0.000191		
107.0	0.000036	3.58	397
117.7	0.000090		
128.4	0.000173		
149.8	0.000340		
171.2	0.000423		
192.6	0.000441		

[1] Comm. Leiden N⁰. 193c.
These Proc. Vol. **32**, 1929, p. 218.

The value of the magnetic field for which the resistance has recovered half its normal value increases by about 300 gauss per degree temperature
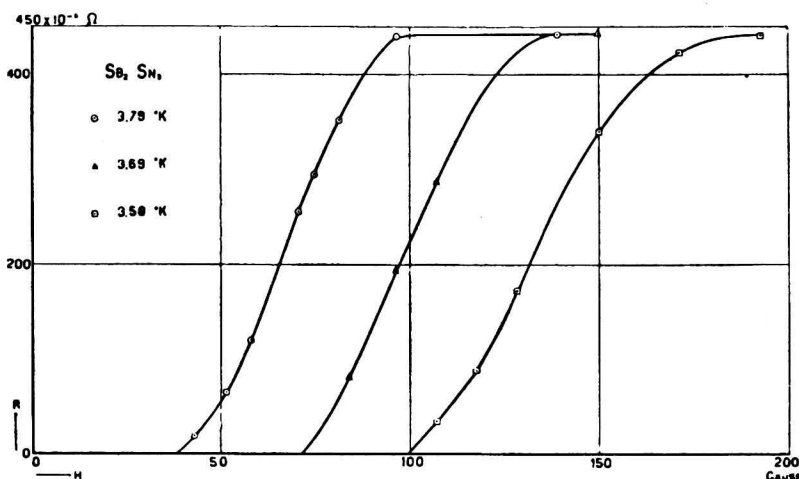

Fig. 2.

TABLE 4. $Sb_2 Sn_3$.

T	$H(W^{1}/_{2})$
3.79 °K.	69 gauss
3.69	101
3.58	134

fall, and the value of the magnetic field for which the supraconductivity disappears by about 200 gauss.

For the longitudinal disturbance of pure tin the magnetic threshold value near the transition point rises by about 140 gauss per degree temperature fall.

§ 4. *The eutectic lead-bismuth.*

Of this rod too the resistance had been investigated already [1]).

According to the melting point diagram the eutectic consists of a mixture of a solid solution of lead in bismuth and a solid solution of bismuth in lead. As to the percentages of the solution the different investigations do not agree.

It is however most probable, taking our results into consideration, that about 33 % bismuth is dissolved in lead and about 10 % lead in bismuth.

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[1]) Comm. Leiden N⁰. 176b.
   These Proc, Vol. 32, 1929, p. 715.

In earlier researches on eutectics we showed already that it is the solid solution of bismuth in lead that will first become supraconductive and then shortcircuit the resistance of the whole rod. Therefore, though the whole eutectic is used as resistance rod, it is the magnetic disturbance of this solid solution that is determined.

A preliminary investigation showed that the magnetic disturbance would require considerable fields. That is why the further investigations were made in the special cryostat for cryogenic magneto-optic researches. This was placed between the pole shoes of an electro-magnet. It was now possible to make experiments, though in a small space, at helium temperatures and in magnetic fields up to 30000 gauss [1]).

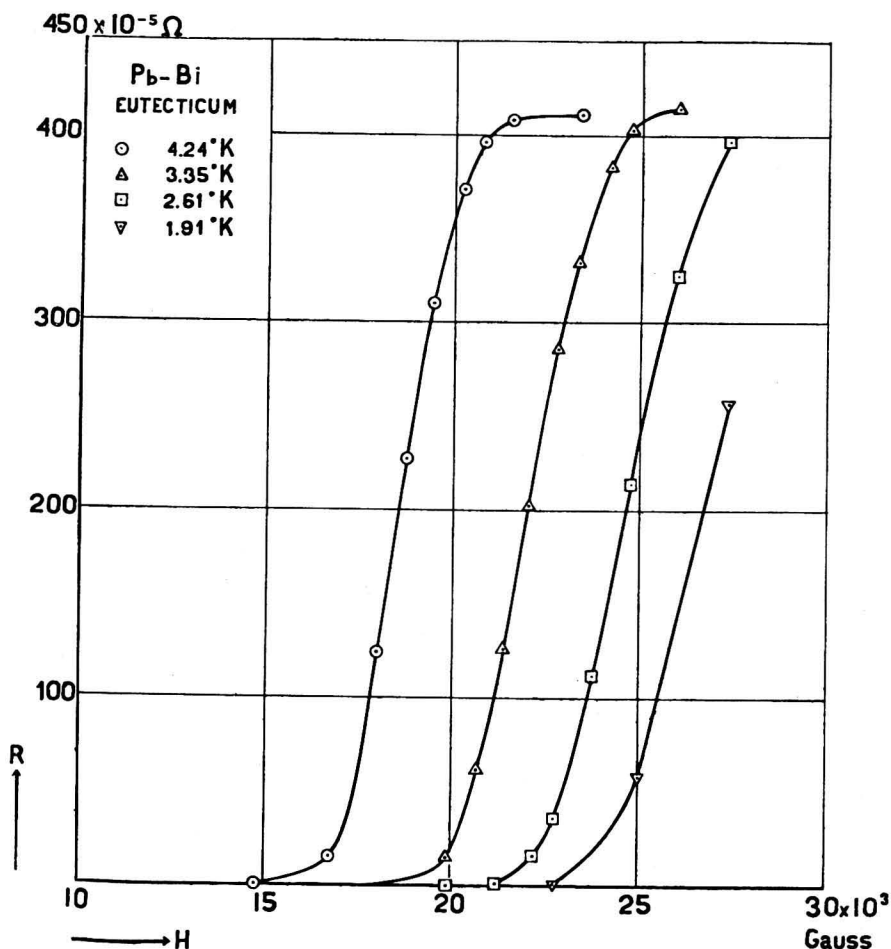The results of the measurements are to be found in table 5 and in fig. 3,

Fig. 3.

[1]) See for more detailed description: JEAN BECQUEREL and W. J. DE HAAS. Comm. Leiden N⁰. 193c.

These Proc. Vol. **32**, 1929, p. 218.

TABLE 5. *Pb—Bi* eutecticum.

H	R	T	p_{helium} in m.m.
14750 gauss	0.00000[1] Ω	4.24	776
16750	0.00015		
17600	0.00064		
18000	0.00124		
18750	0.00227		
19450	0.00310		
20250	0.00371		
20800	0.00396		
21600	0.00408		
23400	0.00411		
18750	0.00257		
17850	0.00141		
14750	0	3.35	301
19900	0.00016		
20700	0.00063		
21350	0.00127		
22050	0.00203		
22800	0.00287		
23350	0.00333		
24200	0.00384		
24750	0.00404		
26000	0.00415		
21700	0.00156		
14750	0	2.61	95.7
19900	0.00000[2]		
21200	0.00001		
22200	0.00016		
22750	0.00036		
23750	0.00112		
24750	0.00214		
26000	0.00325		
27350	0.00397		
23350	0.00082		
19900	0	1.91	18.8
21150	0.00000[1]		
22750	0.00001		
25000	0.00059		
27350	0.00257		
26000	0.00135		

TABLE 6. *Pb—Bi* eutecticum.

T	$H_{(W^1/_2)}$
4.24	16000
3.35	22000
2.61	24600
1.91	26700

while in table 6 the values of $H_{w^1/_2}$ for the different temperatures have been given.

The required magnetic fields are evidently very high.

If a solenoid were made of the saturated solid solution of bismuth in lead, we should be able to generate magnetic fields of 14000 gauss at the boiling point of helium without development of heat and at 2° K. even fields of 19000 gauss.

For more detailed researches of the solid solutions of bismuth in lead we made homogeneous solid solutions of 7 %, of 10 % and of 20 % bismuth and for these we investigated the magnetic disturbance in the same way as for the eutectic. The results are to be found in tables 7, 8 and 9.

TABLE 7. *Pb—Bi* (20 % *Bi*).

H	R	T	p_{helium} in m.m.
7500 gauss	0 Ω	4.24	77.6
8320	0.000048		
9700	0.000531		
11850	0.000948		
14750	0.000996		
23350	0.001071		
9700	0.000568		
9700	0.000002	3.06	203
11150	0.000262		
14750	0.000951		
17800	0.001002		
23350	0.001074		

TABLE 8. *Pb—Bi* (10 % *Bi*).

H	R	T	p_{helium} in m.m.
6000 gauss	0 Ω	3.06	203
6750	0.000065		
8250	0.000478		
11150	0.000531		
14750	0.000536		
19900	0.000555		
23350	0.000555		
26000	0.000555		
8250	0.000482		
6750	0.000127		

TABLE 9. *Pb—Bi* (7 % *Bi*).

H	R	T	p_{helium} in m.m.
3800 gauss	0 Ω	3.06	203
4550	0.000058		
6000	0.000365		
7500	0.000369		
11150	0.000370		

It is seen, that the required magnetic fields are the higher the more bismuth is dissolved in the lead.

§ 5.   Though the researches with the system lead bismuth seem thus to give already useful results we intended to obtain still higher threshold values.

For that purpose we examined an alloy lead-tin-bismuth (15.5 % *Sn*, 32 % *Pb*, 52.5 % *Bi*) and an alloy lead-tin-bismuth-cadmium, (13 .1 % *Sn*, 27.3 % *Pb*, 49.5 % *Bi*, 10.1 % *Cd*).

The measurements were made in the same way as for the alloys lead-bismuth. The results are to be found in the tables 10 and 11.

We found, that in both cases the magnetic disturbance occurs nearly at the same magnetic fields as for the eutectic lead-bismuth, so that these

TABLE 10. *Bb—Sn—Bi.*

H	R	T	p_{helium} in m.m.
14050 gauss	0 Ω	4.24	776
14750	0.000012		
14800	0.000070		
15450	0.000233		
16700	0.000725		
17850	0.001104		
18800	0.001346		
19900	0.001514		
21150	0.001622		
22050	0.001635		
24200	0.001648		
26000	0.001650		
27400	0.001655		
24200	0.001651		
22100	0.001637		
19900	0.001543		
17850	0.001193		
16700	0.000814		
14750	0.000063		
17300	0	3.06	203
17850	0.000011		
19900	0.000544		
22100	0.001145		
24200	0.001489		
26000	0.001631		
27400	0.001661		

alloys of more than two metals do not yield a special advantage for our problem.

Finally we still draw the attention to the fact that for the alloys lead-bismuth as well as for those of tin-lead-bismuth, and for those of tin-lead-

bismuth-cadmium a small hysteresis seems to occur in the magnetic transition figure. We plan however more detailed researches to reach definite conclusions.

TABLE 11. *Pb—Sn—Bi—Cd.*

H	R	T	p_{helium} in m.m.
14050 gauss	0 Ω	4.24	776
14750	0.000006		
15450	0.000169		
16700	0.000344		
18750	0.000460		
20700	0.000510		
22100	0.000529		
24200	0.000538		
26000	0.000547		
27400	0.000558		
20700	0.000514		
18750	0.000467		
15450	0.000231		
17300	0	3.06	203
17850	0.000002		
19950	0.000316		
22100	0.000441		
24200	0.000508		
26000	0.000542		
27400	0.000553		