Physics. — *The magnetic disturbance of the supraconductivity of single-crystal wires of tin.* By W. J. DE HAAS and J. VOOGD. (Communication N⁰. 212*d* from the Physical Laboratory at Leiden.)

(Communicated at the meeting of January 31, 1931).

§ 1. *Introduction.* The investigation of the magnetic disturbance of the supraconductivity revealed two peculiarities which have been examined already in detail for mercury [1]).

1st. Hysteresis.

The resistance comes back in a field higher than that in which it vanishes.

2nd. Discontinuities.

For mercury resistances in a field parallel with the axis of the wire it was found that in a decreasing field the resistance vanished with a few discontinuous steps which were lying at little differing fields. Between two steps the resistance remains constant. In an increasing field the resistance is restored in a continuous way. These discontinuities were ascribed to the sudden vanishing of the resistance of the few crystallites which constituted the wire.

A general remark was also made already on the intimate connection between the state of crystallization of the material and the magnetic transition figure. We pointed especially to the desirability of the investigation of the magnetic disturbance with single-crystalline wires.

Some preliminary experiments with single-cristalline wires have been made already [2]).

The results did not agree however which probably is due to disturbances of the single-crystalline state of the wires.

We continued these researches with single-crystalline wires of white tin, the single-cristalline character of which had been controlled carefully. Namely we used wires, for which we had investigated the supraconductivity [3]). The dimensions of the wires had been chosen for this research especially.

The length should not be too great, as otherwise the magnetic field generated by a solenoid would not be homogeneous over the whole length. The diameter had to be small, so that accurate resistance measurements with weak currents might be possible. A strong measuring current namely

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[1]) G. J. SIZOO, W. J. DE HAAS and H. KAMERLINGH ONNES, Comm. Leiden N⁰. 180 *c*.
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[2]) G. J. SIZOO W. J. DE HAAS and H. KAMERLINGH ONNES, Comm. Leiden N⁰. 180 *c*.

[3]) Comm. Leiden No. 214 *a*.

would give rise to its own disturbing magnetic field, which would complicate the phenomena.

The following dimensions were found suitable, length about 15 mm, diameter from 0.15 mm to 0.25 mm.

We investigated the magnetic disturbance in magnetic fields parallel with the axis of the wires (longitudinal disturbance) and in fields perpendicular to this axis (transverse disturbance).

§ 2. *Longitudinal disturbance.*

For different wires the longitudinal magnetic transition curve was determined; it showed the same character as that in the former case. When the field is increased the resistance always comes back for a definite value of the field intensity within a small magnetic range. The rising line is therefore a steep curve, which begins straight and is somewhat curved at the upper end. When the resistance is restored to its normal value a further increase of the field does not change it anymore (but for the increase of the resistance in much higher fields).

In a decreasing field the resistance first keeps its normal value, also in fields lower than those of the rising part of the curve, until it vanishes discontinuously in one step.

Several repetitions of the cycle at the same temperature showed that the resistance always comes back in the same field. The discontinuous vanishing of the resistance however does not always take place at the same field intensity.

The latter intensities can differ considerably.

We could however not yet find the cause of this phenomenon.

The character of the transition curve is proved to be independent of the strength of the measuring current, if the latter is not too high.

In table 1 and in fig. 1 we give an example of curve of the longitudinal transition, which distinctly shows the characteristic features.

TABLE I. *Sn* — 12 — '28.

$T = 2.92°$ K. Longitudinal field.

H	R	Remarks	H	R	Remarks
100.4	0		100.6	0	
103.6	0.0000298 Ω	jump	103.6	0.0000288 Ω	jump
104.9	323		104.2	323	
107.0	323		105.7	323	
89.9	323		99.9	0	jump
89.2	0	jump			

The rising and the descending parts of the curve differ in two important points:

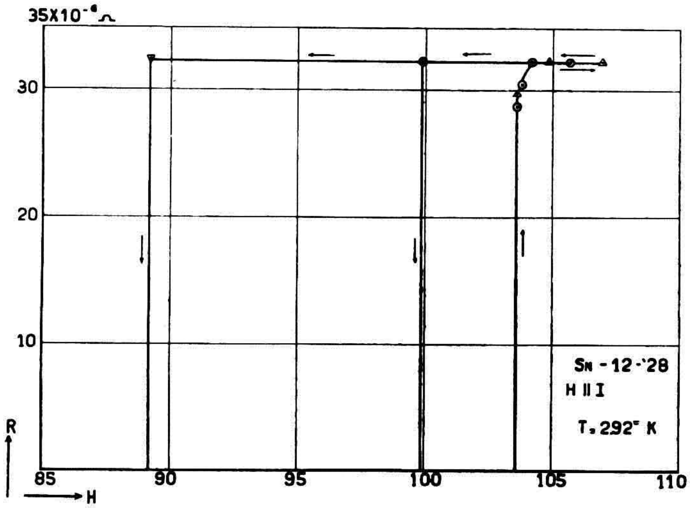

Fig. 1.

1st. *On the rising part it is possible to realise transition states between normal resistivity and supraconductivity; on the descending part this is impossible.*

2nd. *The rising part of the line always lies at the same intensities of the field, the descending part not, though always at lower intensities than the rising curve.*

§ 3. *Transverse disturbance.*

In this case the curve of the magnetic transition shows a character quite different from that described above.

In an increasing field the resistance comes back continuously within a magnetic range of about $^2/_3$ of the field intensity for which the restoration of the resistance begins. The resistance has regained its normal value at about the same field intensity as has been found for the longitudinal field. In first approximation the character of the rising line is independent of the measuring current, becoming less curved only with higher measuring current.

This is not the case for the descending branch.

In a decreasing field the resistance first keeps its normal value. *Then for a definite intensity of the field the resistance falls suddenly and the amount of this sudden decrease in resistance is the higher the weaker the measuring current is.*

For very weak measuring currents the resistance can even vanish suddenly for a field intensity for which in an increasing field the resistance is already partially restored.

If however, after this sudden fall of the resistance there is left still part of the resistance, this rest vanishes very slowly only in the decreasing field, so that finally the sample becomes supraconducting in a field lower than that for which in the increasing field the resistance begins to come back.

In table 2 and in fig. 2 we give an example of such a transverse transition figure.

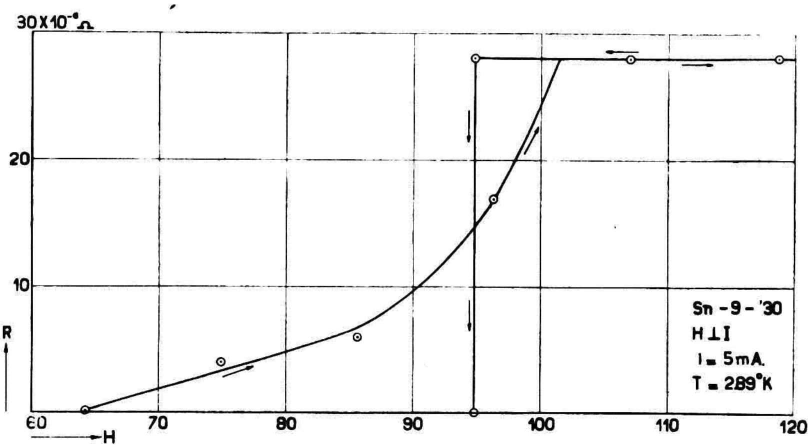

Fig. 2.

§ 4. *Discussion.*

We first discussed our transition figures with a view to the question how we might still refine and complete our experiments.

a. As to the state of crystallization near the soldering places little irregularities may exist.

b. Little attention has been paid to the right orientation of the axis of the wire with respect to the magnetic field, so that deviations between this axis and the field are very well possible.

Both *a.* and *b.* may have influenced the details of our transition figure without however, in our opinion at least, doing damage to the important characteristics of the longitudinal and the transverse disturbance.

A comparison with results of earlier measurements with poly-cristalline tin wires in homogeneous fields [1]) supports this opinion.

Here too in the longitudinal case the resistance comes back within a much smaller magnetic range than in the transverse case. The hysteresis figure of these wires reminds one even of that found by us in our single-crystalline wires.

As to the *orientation of the crystal axis with respect to the axis of the wire*, it would be very interesting to know whether this has an influence on the magnetic disturbance.

We investigated the longitudinal disturbance for several single-cristalline wires the tetragonal axis of which was nearly exactly perpendicular to the axis of the wire. The magnetic transition figure had the same character.

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[1]) G. J. SIZOO, W. J. DE HAAS and H. KAMERLINGH ONNES, Comm. Leiden No. 180 c.

TABLE II. *Sn* — 9 — '30.

$T = 2.89°$ K. Transverse field.

H	*R*	Current	Remarks	*H*	*R*	Current	Remarks
64.2	$0.000001^{5}\,\Omega$	20 m.A.		98.4	$0.000023^{6}\,\Omega$		
70.6	4^{3}			107.0	28^{1}		
77.0	6^{3}			117.7	28^{6}		
85.6	13^{2}			128.4	28^{6}		
92.0	19^{5}			149.8	28^{6}		
96.3	23^{0}			214.0	28^{6}		
102.7	28^{1}			117.7	28^{1}		
107.0	27^{8}			107.0	28^{1}		
128.4	28^{1}			96.3	28^{6}		
214.0	28^{1}			94.6	16^{6}		jump
107.0	28^{1}			92.0	10^{6}		
96.3	28^{1}			85.6	7^{5}		
94.2	28^{1}			77.0	4^{0}		
92.7	17^{7}		jump	64.2	1^{0}		
90.9	17^{0}			0	0	5 m.A.	
89.9	16^{7}			64.2	0		
87.7	15^{2}			74.9	4		
83.5	11^{6}			85.6	6		
77.0	8^{3}			96.3	17		
70.6	6^{6}			107.0	28		
64.2	3^{3}			117.7	28		
53.5	0			321.0	28		
42.8	0	10 m.A.		117.7	28		
64.2	1^{0}			107.0	28		
70.6	1^{5}			96.3	28		
77.0	4^{0}			94.8	0		jump
85.6	7^{5}			0	0		
92.0	15^{1}			94.8	10		

Besides we investigated the transverse disturbance for the wire *Sn*-9-'30, in which the tetragonal axis made an angle of 45° with the axis of the wire.

Here too the magnetic transition figure always had the same character. Though only few data have been collected as yet, we get the impression, that the character of the magnetic transition figure is independent of the orientation of the crystal axis with respect to the axis of the wire.

Here again our opinion is supported by comparison with the magnetic transition curves of polycrystalline tin wires.

So our experiments have revealed many new phenomena. Still a refinement and an extension of them is desirable. In our opinion the principal point found is the characteristic difference between the longitudinal and the transverse disturbance.

In further experiments we shall try to learn something more of the mechanism of the magnetic disturbance (both longitudinal and transverse) in the wire. Hence we must find out how far in the different stages of the magnetic transition curves the magnetic field has intruded into the wire.

§ 5. *Influence of the temperature on the magnetic disturbance.*

In order to find the dependance of the magnetic disturbance on the temperature, we considered in our earlier researches at different temperatures the intensity of the field in which the resistance had regained half its normal value. For one and the same temperature this magnetic half-value was found to be always higher for the longitudinal disturbance than for the transverse disturbance. Then the hysteresis phenomenon had not yet been found, though all these measurements were made with poly-cristalline wires (The hysteresis of these must have been very small).

Now that the hysteresis had been found the magnetic half value has lost its meaning, so that a new agreement had to be made as to the way in which the influence of the temperature could be indicated.

A very characteristic field intensity, perfectly reproducible, is that for which in a longitudinal field the resistance of a single-crystalline wire comes back. This restoration is so sharply defined that it can hardly be discerned between the point where the resistance begins to come back and that in which it has regained its normal value.

For poly-crystalline wires the case is different. Here the transition curve is not sharp. That is why we must take here the magnetic half value for the rising curve of the longitudinal disturbance as a characteristic field intensity.

In fig. 3 we have plotted for single-crystalline wires the temperature as a function of the field intensity for which in a longitudinal and in a transverse magnetic field the resistance begins to come back.

The values in the figure are the mean of those found for different single-crystalline wires, which differed very little from each other. It is seen that in a longitudinal field the resistance comes back in about the same field in which in a transverse magnetic field the resistance has just regained its normal value.

Further the magnetic range in which the resistance comes back in the transverse case, is seen to be proportional to the intensity of the field in which the resistance is totally restored.

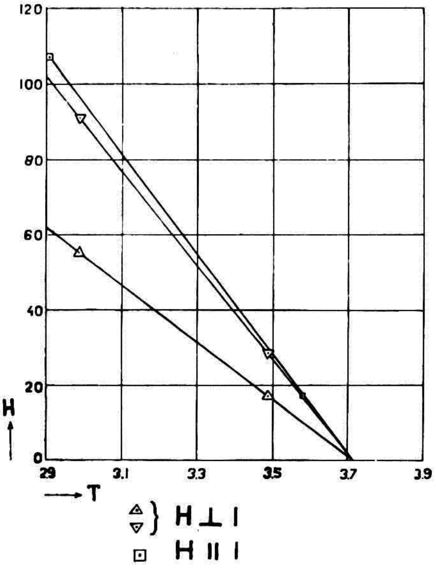

Fig. 3.

From the figure it is also evident, that for the transverse disturbance the magnetic half value of the rising curve will be smaller than for the longitudinal disturbance, which has always been observed in the case of polycrystalline wires with small hysteresis.

We wish to express our thanks to Mr. P. M. VAN ALPHEN for his valuable help during the experimentation.