

**Physics.** — *The determination of the susceptibility of erbium sulphate at low temperatures.* By W. J. DE HAAS, E. C. WIERSMA and W. H. CAPEL. (Communication N<sup>o</sup>. 201*b* of the Physical Laboratory at Leiden.)

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§ 1. *Introduction.* The susceptibility of erbium sulphate has been determined in the region between 290° K. and 14.3° K. in order to see whether the results found by H. R. WOLTJER and H. KAMERLINGH ONNES <sup>1)</sup> for the magnetization of gadolinium sulphate are specific to gadolinium or are general to the sulphates of all the rare earths.

§ 2. *Apparatus and method.* The apparatus used for the measurements mentioned above was considerably altered so that it could be used for determinations of greater accuracy required at higher temperatures. A drawing to scale is given in fig. 1.

The rod *A*, held vertical by two thin springs *B-B* and supported from a glass bulb *C* floating on mercury, was still used, but alterations were made to the compensating and part of the cryo-magnetic arrangements. Three coils were used for the compensation, two fixed *D-D* at a distance of 16 mm apart, and the third *E* attached to the top of the floating rod *A* which moves between them. In this way large forces could be obtained with relatively small currents, — necessary as the forces become rather large at hydrogen temperatures. The coils exerted a force of about 6 g. when a current of 1 amp. was passed through them in series. The maximum current that could be passed through the coils was about 5 amps, which would exert a force of 150 g., a value much higher than that required in our experiments.

As the zero position of the sample *F* could not be changed by the addition of weights and as the densities of methyl chloride, ethylene, nitrogen and hydrogen, the liquids used to obtain the different temperatures, are very different, it was not possible to immerse the sample in the liquids. In order to overcome this difficulty, the tube *G* containing the mercury reservoir, glass windows, spring fastening *H-H* etc., was connected to a short tube *J* by means of a large conical joint *K*, the sampler *F* having previously been fixed in its right position in relation to the magnetic field. Inside this tube was soldered a cone *L* of german silver carrying a long and very thin walled (0.1 mm) tube *M* of the same material to the end of which was

<sup>1)</sup> These Proceedings Vol. 26, p. 613 and p. 626.

soldered a thick copper tube *N*, closed at the end with a soldered copper disc.

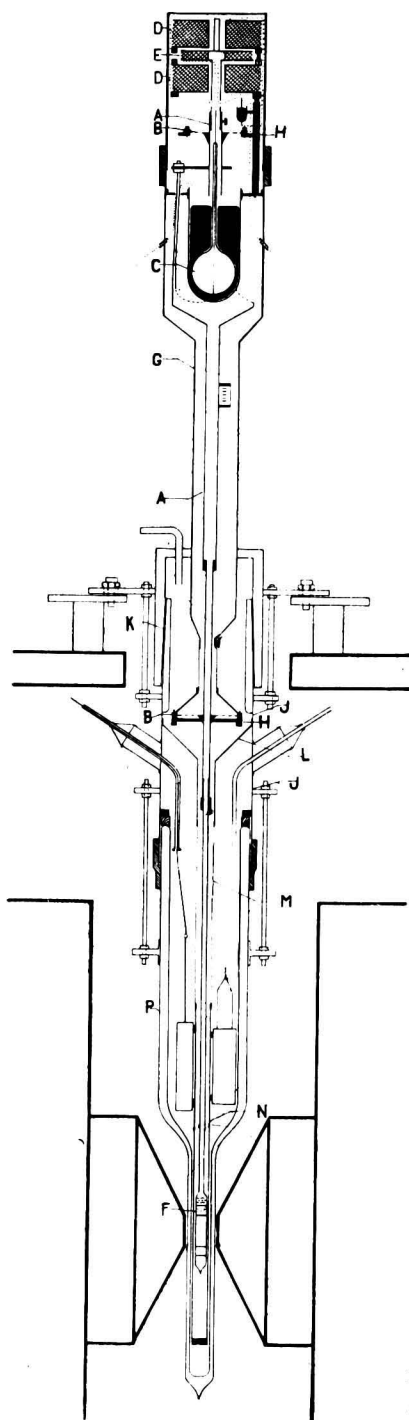


Fig. 1.

The sample could swing freely inside these tubes with an annular space of 2 mm. The vacuum glass *P* was fixed to the larger tube by means of a rubber band in the usual way.

The sample could therefore be placed in a gaseous atmosphere, as the space in which it hung was not connected to that in which the liquids boil. (The gases used were nitrogen for the temperatures attainable with methyl chloride and ethylene, hydrogen for the nitrogen and helium for the hydrogen temperatures.)

This arrangement also had the advantage of eliminating two sources of difficulty. The boiling of the liquid often moved the carrier very irregularly and it was necessary to wait until these disturbances were small enough before proceeding, and also the zero point of the sample changed during the measurements owing to the evaporation of the liquid altering the hydrostatic pressure. The copper tube guaranteed a good temperature equilibrium in the space containing the sample, and the thin walled german silver tube provided an insulation against the flow of heat from the warmer parts of the apparatus.

The sample, contained in a glass tube made symmetrical to the pole pieces of the magnet, was 6 mm long, about 5 mm in diameter and weighed 0.24395 g, its formula being  $\text{Er}_2(\text{SO}_4)_3 \cdot 8 \text{H}_2\text{O}$ .

The magnet used was by WEISS, the diameter of the pole pieces was 16 cm, the flat ends of the conical tops being 25 mm in diameter and 24 mm apart. The sample was placed in the position of maximum  $\frac{d(H^2)}{dz}$ , as determined from the calibrations of the field made before the measurements.

### § 3. Corrections. Determinations at

ordinary temperatures showed that no force was exerted on the carrier, as no sign of displacement could be observed even in the strongest field. This agrees with the fact that all the metallic parts were at a much greater distance from the field than in the previous measurements. It was not necessary to determine this correction at other temperatures as these parts remain practically at ordinary temperatures when the vacuum glass is filled. Owing to its symmetrical form no force was exerted on the glass. A correction has been applied for the demagnetization of the powder for hydrogen temperatures only, as it becomes negligible for the higher temperatures. According to Dr. BREIT, the demagnetization is given by  $-\frac{4}{3}\pi\sigma a$  in which  $d$  is the density of the substance, not of the powder. The correction amounted to 1.3 % at the boiling point and 1.9 % at a temperature near the triple point of hydrogen.

As the measurements were made in a gas the susceptibility of the surrounding matter was zero.

The values of  $\frac{d(H^2)}{dz}$  used were those determined from the calibrations of the field so that the relative accuracy of the points measured at one temperature, contain any systematic errors made in the calibration, and the accuracy from this point of view is probable not greater than 1 %.

§ 4. *Measurements.* The sample was placed in the axis of the field and its height above the centre of the field measured by means of a cathetometer, this height being corrected if necessary by adjusting the magnet. As the maximum of  $\frac{d(H^2)}{dz}$  is very flat, the adjustments were made in the middle of the flat part, as then small changes of the zero position would not affect the results. The copper tube and then the vacuum glass were fixed in place and the magnet moved back into position, which position had been marked by means of plumb lines fixed to the apparatus and two pointers on the yoke of the magnet.

When a given temperature had been reached, a zero point was read, the current of the magnet switched on and four points with different compensating currents determined; the currents were then switched off and the zero point again read.

These observations were plotted on a graph from which the compensating current for the mean zero position could be determined.

Measurements were made with currents of 70, 60, 40, 30, 20, 20, 30, 40, 60, 70 amps successively through the magnet (30 and 20 amps were omitted at room temperature and at some of the methyl chloride temperatures as the forces become too small for accurate measurement). The mean value at a given temperature was taken for the determination of  $\chi$ .

*Results.* From the measurements it appeared that Erbium does not

follow the Curie law within the limits of probable error, but that a  $\Delta$  of  $1.9^\circ$  K. exists; the formula becomes  $\chi(T + 1.9) = C$ .

The values of  $\chi$  and  $\chi(T + 1.9)$  for the different temperatures are given in the table I. It is seen that the figures in the last column are sensibly constant, the only large deviations occurring for the higher methyl chloride

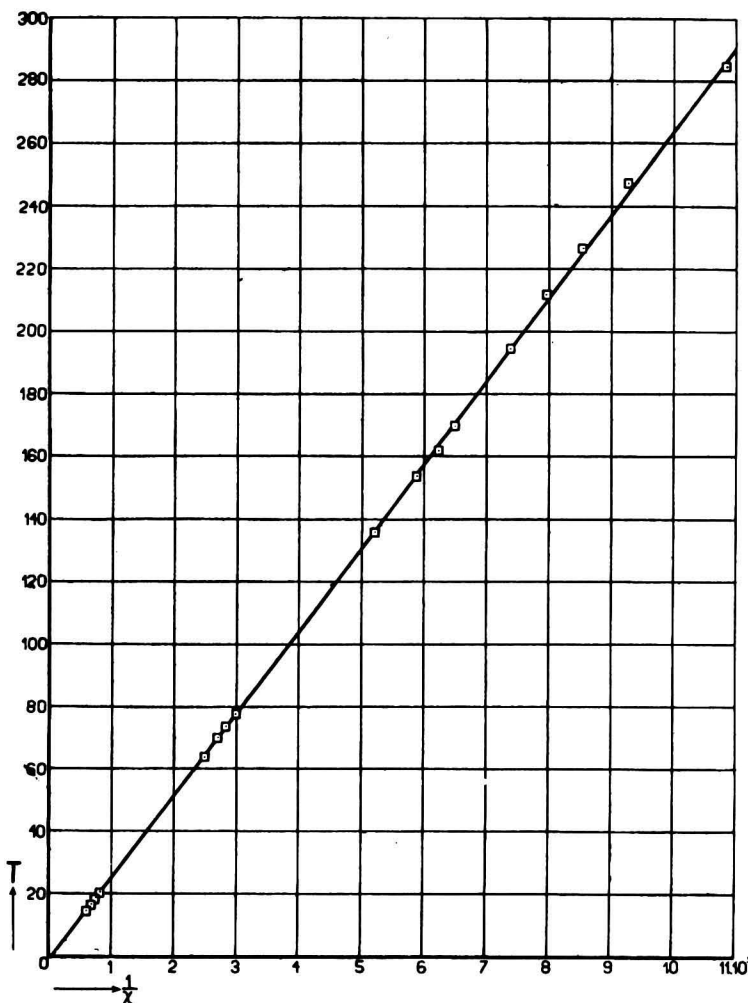


Fig. 2.

temperatures where the measurements were least accurate owing to the forces being small.

$\frac{1}{\chi}$  is plotted against  $T$  in Figure 2, the straight line  $\chi(T + 1.9) = C$  being included. In Figure 3 the magnetization  $\sigma$  is plotted against  $H$  ( $H$  for the middle of the sample) for liquid hydrogen temperatures; the drawn lines give the values calculated from the mean  $C$ , from which it is evident that

the susceptibility is nearly independent of the strength of the field for these temperatures, i.e. no saturation could be observed with certainty. The figures are given in table II.

TABLE I.

$T$	$\chi \cdot 10^3$	$\chi \cdot (T+1.9) \cdot 10^3$
285.0	0.092	26.40
247.4	0.107 <sup>9</sup>	26.90
226.6	0.117 <sup>0</sup>	26.73
211.7	0.125 <sup>7</sup>	26.85
194.2	0.135 <sup>3</sup>	26.53
169.5	0.152 <sup>7</sup>	26.17
161.59	0.160 <sup>2</sup>	26.19
153.43	0.169 <sup>9</sup>	26.39
135.82	0.191 <sup>5</sup>	26.37
77.31	0.334 <sup>1</sup>	26.46
73.50	0.350 <sup>9</sup>	26.46
69.64	0.369 <sup>1</sup>	26.41
63.83	0.400 <sup>2</sup>	26.31
20.34	1.192	26.51
18.43	1.300	26.43
16.53	1.435	26.45
14.34	1.624	26.37

TABLE II.

$T$	$H$	$\chi$	$\sigma$
20.34 K.	17.2.10 <sup>3</sup>	11.87.10 <sup>-4</sup>	20.42
	16.5	11.82	19.50
	14.0	12.03	16.84
	11.7	11.98	14.02
	8.2	11.87	9.73
18.43	17.2	12.98	22.33
	16.5	12.98	21.42
	14.0	13.04	18.26
	11.7	13.10	15.33
	8.2	12.93	10.60
16.53	17.2	14.35	24.68
	16.5	14.51	23.94
	14.0	14.62	20.47
	11.7	14.56	17.04
	8.2	14.35	11.77
14.34	16.5	16.31	26.91
	14.0	16.21	22.69
	11.7	16.21	18.97
	8.2	16.18	13.27

The number of WEISS magnetons has been calculated from the mean value of  $\chi (T + 1.9) = \frac{\sigma_0^2}{3R}$  to be 44.82, taking 1123.5 for the WEISS magneton or 9.001 BOHR magnetons the Curie constant becoming  $C = 10.16$ .

We are indebted to Baron AUER VON WELSBACH for placing the

specimen of erbium sulphate at our disposal, and we wish to record our thanks to Mr. BLOM for his assistance in the measurements.

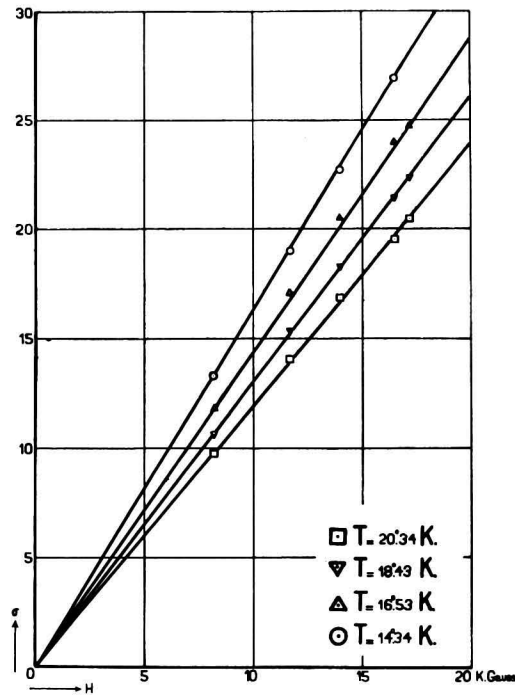


Fig. 3.