The Curie-Weiss constant of solid ^3He on the melting curve at high magnetic fields

H. Godfrin, G. Frossati, A.S. Greenberg, B. Hebral, D. Thoulouze

► To cite this version:

H. Godfrin, G. Frossati, A.S. Greenberg, B. Hebral, D. Thoulouze. The Curie-Weiss constant of solid ^3He on the melting curve at high magnetic fields. *Journal de Physique Lettres*, 1983, 44 (14), pp.625-627. 10.1051/jphyslet:019830044014062500 . jpa-00232241

HAL Id: jpa-00232241

<https://hal.science/jpa-00232241>

Submitted on 1 Jan 1983

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Classification
Physics Abstracts
 67.80

The Curie-Weiss constant of solid ^3He on the melting curve at high magnetic fields

H. Godfrin (*), G. Frossati (**), A. S. Greenberg (*), B. Hébral (*) and D. Thoulouze (*)

(*) Centre de Recherches sur les Très Basses Températures,
 C.N.R.S., BP 166 X, 38042 Grenoble Cedex, France

(**) Kamerlingh Onnes Laboratory, Nieuwsteeg 18, 2311.SB, Leiden, The Netherlands

(Reçu le 21 février 1983, révisé le 25 mai, accepté le 31 mai 1983)

Résumé. — La constante de Curie-Weiss de l' ^3He solide sur la courbe de fusion a été mesurée par RMN à fort champ magnétique (7,2 teslas). La valeur obtenue ($\theta \cong -3 \text{ mK}$) est en accord avec les mesures de susceptibilité à bas champ, et implique une nouvelle analyse de mesures récentes de la pression magnétique à fort champ, cohérente avec le modèle d'échange multiple.

Abstract. — The Curie-Weiss constant θ of solid ^3He on the melting curve has been measured by NMR at high magnetic fields (7.2 teslas). The result ($\theta \cong -3 \text{ mK}$) is in agreement with low field susceptibility experiments. However, this implies a new analysis of recent measurements of the magnetic pressure at high fields, coherent with the multiple exchange model.

The exchange interaction, responsible for nuclear magnetic order in solid ^3He at millikelvin temperatures, has been investigated extensively during the last decade.

The most recent experiments [1-4] support the multiple exchange theory [5] which considers that 3 and 4 particle exchanges are the dominant processes.

However, the susceptibility results at low fields are generally analysed by a Curie-Weiss law, with a Curie-Weiss constant θ related to the molar volume V by a simple power law (see [6] and references therein)

$$\theta = -2.656(V/24)^{17.34} \quad (V \text{ in cm}^3, \theta \text{ in mK}).$$

Since three and four particle exchanges should have different molar volume dependences, θ is expected to depend at least on two parameters. A precise determination of θ as a function of the molar volume is therefore a crucial test of the multiple exchange theory.

In a recent letter, Van Degrieff *et al.* [6] reported high precision isochoric pressure measurements in bcc solid ^3He in high magnetic fields. Their results give essentially the volume derivative of the Curie-Weiss constant θ for three molar volumes V around 24 cm^3 , and were analysed assuming a power law :

$$d\theta/dV = -1.156 (V/24)^{20.7} \text{ mK} \cdot \text{cm}^{-3}.$$

Under the assumption that this law holds for smaller molar volumes, where θ becomes vanishingly small, they obtain :

$$\theta = -1.28 (V/24)^{21.7} \text{ mK},$$

a value substantially lower than the susceptibility results quoted earlier.

They conclude that there is a thermodynamical inconsistency between both sets of measurements, although they suggest that either a dependence of θ with the magnetic field, or a more complicated volume dependence of θ could be responsible for the discrepancy.

We have studied experimentally the first point, measuring θ at high fields; the description of the experiment and its implications on the exchange processes are the subject of this letter.

Our experiments [2, 7, 8] on polarized solid and liquid ^3He required the production of known amounts of solid ^3He on the melting curve, at high magnetic fields. A plastic Pomeranchuk cell [9] was precooled down to 3 mK by a dilution refrigerator [10]; the problem of thermometry at high magnetic fields was avoided by using a plastic capacitor [11] located at the outlet of the mixing chamber in a low field region. The very low impedance of the tube (diameter : 2 cm) between the mixing chamber and the thermometer insured a negligible thermal gradient. It was calibrated at zero field against the melting curve of ^3He and the susceptibility of CMN. Carbon resistors (Matsushita 68 Ω , 1/8 W) were also used at temperatures above 10 mK.

The magnetization of ^3He in the cell was measured by CW NMR at 230 MHz (i.e. $B_0 \cong 7.2$ teslas). The solid was grown at constant pressure by heating the cell and controlling automatically the ^4He pressure of the Pomeranchuk cell. Compression times were of the order of several minutes to avoid the irreversible effects pointed out in reference 2; solidification occurs then at constant temperature. The polarization p of the solid was obtained by comparing the area of the absorption signal measured as a function of the fraction X_s of solid to that measured with the cell full of liquid, assuming that the magnetization of the liquid is given by :

$$M_l = N\mu^2 B_0/k_B T_F^*$$

the one of the solid being $M_s = pN\mu$ (μ is the magnetic moment of the ^3He atom, and $T_F^* = 178$ mK on the melting curve [12]).

The maximum solid fraction formed during the experiments was of the order of 50 % in steps of about 8 %. The NMR signal varied linearly with the solid fraction X_s , for $X_s < 50$ %. It was difficult to grow solid with the equilibrium magnetization for larger values of X_s . The maxi-

Fig. 1. — Deviation of the polarization p of solid ^3He (at 7.2 teslas on the melting curve) from the polarization p_0 of non-interacting spins (Brillouin law) as a function of temperature; dots : our measurements; solid lines : mean field calculation with $|\theta| = 1; 2$ and 3 mK.

imum polarization of the solid obtained at temperatures of the order of 3 mK, was $(75 \pm 4)\%$. Temperature gradients were minimized with our solidification procedure, the cell being at the same temperature as the mixing chamber of the dilution refrigerator.

The results can be analysed as shown in figure 1 : the difference between the polarization of non-interacting spins (Brillouin law) and the measured one, is plotted as a function of temperature. The solid lines show the result of a mean field calculation (assuming $|\theta| = 1; 2$ and 3 mK) which should be compared to experimental results above 10 mK (away from the vicinity of the nuclear magnetic order). The error bars at low temperatures are partly due to the irreversible effects already described. The other sources of error affect the whole temperature range : uncertainties on the solid fraction, the area of the signal from the liquid (much smaller than the one from the solid) and the contribution of a spurious signal from the liquid of the mixing chamber. The combined uncertainties have been estimated to be $\Delta p/p \approx 4\%$.

The data, within error bars typical of this kind of measurements, are well described by a value of $\theta \cong -3$ mK at 7.2 teslas, in agreement with low field values, and much larger than the one obtained by the power law analysis of the pressure measurements [6] at high magnetic fields.

Therefore, the source of the discrepancy between susceptibility and pressure determinations of θ does not come from the magnetic field dependence of θ .

On the other hand, it should be noted that pressure measurements of $d\theta/dV$ have only been done at high molar volumes, and that direct measurements of θ are particularly inaccurate at low molar volumes. To bring both sets of measurements into agreement, it is necessary to suppose that, for small molar volumes, θ is larger than the value calculated with the simple power law, as expected from the multiple exchange model.

A correct analysis of the pressure measurements to yield absolute values of θ from the measured $d\theta/dV$ requires necessarily new measurements of $d\theta/dV$ at smaller molar volumes.

Acknowledgments.

We are indebted to M. Roger and B. Castaing for useful discussions.

References

- [1] OSHEROFF, D. D., CROSS, M. C., FISCHER, D. S., *Phys. Rev. Lett.* **44** (1980) 792.
- [2] GODFRIN, H., FROSSATI, G., GREENBERG, A. S., HÉBRAL, B. and THOULOZE, D., *Phys. Rev. Lett.* **44** (1980) 1965.
- [3] ADAMS, E. D., SCHUBERTH, E. A., HAAS, G. E., BAKALYAR, D. M., *Phys. Rev. Lett.* **44** (1980) 789.
- [4] PREWITT, T. C., GOODKIND, J. M., *Phys. Rev. Lett.* **44** (1980) 1699.
- [5] ROGER, M., DELRIEU, J. M., HETHERINGTON, J. H., *J. Physique-Colloq.* **41** (1980) C7-241.
ROGER, M., HETHERINGTON, J. M., DELRIEU, J. M., To be published in *J. Low Temp. Phys.*
- [6] VAN DEGRIFT, C. T., BOWERS JR. W. J., PIPES, P. B. and MCQUEENEY, D. F., *Phys. Rev. Lett.* **49** (1982) 149.
- [7] FROSSATI, G., *J. Physique Colloq.* **41** (1980) C7-95.
- [8] GODFRIN, H., Thèse d'Etat, Université de Grenoble (1981) unpublished.
- [9] FROSSATI, G., GODFRIN, H., HÉBRAL, B., SCHUMACHER, G. and THOULOZE, D., Proc. ULT Hakoné symposium, T. Sugawara, S. Nakajima, T. Ohtsuka and T. Usui eds, The Physical Society of Japan (1978), p. 294.
- [10] See reference 9, p. 205, and FROSSATI, G., Proc. 15th Int. Conf. on Low Temp. Phys. Grenoble (1978), *J. Physique Colloq.* **39** (1978) C6-1578.
- [11] FROSSATI, G., GILCHRIST, J., GODFRIN, H., THOULOZE, D., Proc. ULT, Hakoné symp. (see Ref. 4), p. 312.
- [12] WHEATLEY, J. C., in *The Helium liquids*, ed. Armitage and Farquhar (Academic Press) 1975. This is the value of T_F^* measured at low fields, but the susceptibility of liquid ^3He is not expected to depend substantially on the magnetic field even for $B = 7.2$ T.