TWO STAGE NUCLEAR DEMAGNETIZATION EXPERIMENTS

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Résumé.- Nous décrivons les expériences faites avec un appareil de désaimantation nucléaire, qui comprend un réfrigérateur à dilution d'Helium -3 dans l'hélium -4 et un composé de Van Vleck paramagnetique comme étage de prérefroidissement. Nous décrivons le résultat de désaimantation d'In, $PrNi_5$ et $PrIn_3$ et aussi de mesures d'orientation nucléaire de ^{95}NbPt et ^{54}MnZn.

Abstract.- We describe experiments done with a nuclear demagnetization apparatus consisting of a ^{3}He -^{4}He dilution refrigerator and a "Van Vleck" paramagnetic compounds as precooling stages. Demagnetizations of In, $PrNi_5$ and $PrIn_3$ are reported as well as nuclear orientation measurements of ^{95}NbPt and ^{54}MnZn.

Due to its enlarged hyperfine splitting and its metallic structure the "van Vleck" paramagnetic compound $PrCu_6$ is very suitable as a precooling stage in a nuclear demagnetization apparatus /1/. The apparatus is schematically drawn in figure 1 : the mixing chamber (A) of a SHE dilution refrigerator (model nr. DRI 334, cooling power 0.3 mW at 0.1 K with a circulation rate of 4 x 10^{-4}mole/sec) is connected to a 7 cm diameter, 4.5 cm long block (B) of $PrCu_6$ containing 3 moles (1.5 kg) through a Pb heat switch (C) and and Ag-bar (D).

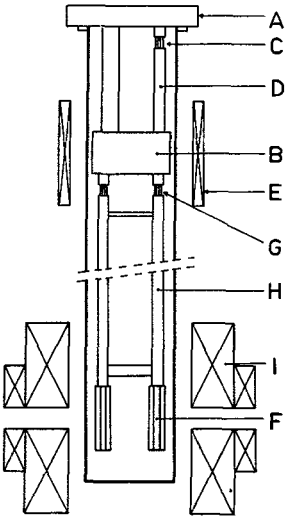

Fig. 1 : Schematic drawing of the apparatus.

The heat switch consisting of 110 wires of 6N-pure Pb (diameter 0.5 mm, length 6 mm) is surrounded by a small superconducting magnet to make or break heat contact. After precooling the $PrCu_6$ in the 3T field of the superconducting magnet (E) in about 15 hours, the heat contact (C) is broken and by demagnetization of the $PrCu_6$ we can precool a second nuclear stage (F) connected to the $PrCu_6$ through 4 Ag-bars (H) and a heat switch (G). The nuclear stage (F) can be placed in a magnetic field with a maximum value of 6.3 T produced by the superconducting split-pair magnet (I).

Experiments :

- a) $PrCu_6$ without nuclear stage : the lowest temperature reached with the $PrCu_6$ is 2.6 mK in a field of 0.05 T after precooling the block till 30 mK in a field of 3T resulting in an entropy reduction of 20 J/K. B/T losses during the demagnetization with a time constant of 3 hours mostly occur below 10 mK. The total time during which the temperature is below 10 mK is nearly one week. The thermal resistance to the $PrCu_6$ is determined to be 6 $T^{-1}K^2/W$. For the sake of comparison of this enhanced nuclear refrigerant with dilution refrigeration, we can express (using the above mentioned thermal resistance) the cooling power by the formula : $\dot{Q} = 0.083\ (T_1^2 - T_2^2)$ watt, where T_1 is the temperature of the sample to be cooled and T_2 is the temperature of the $PrCu_6$ nuclei. Assuming a constant temperature ratio ($T_1/T_2 = 1.7$) and isothermal demagnetization after reaching T_2, we get for the cooling power as a function of temperature : $\dot{Q} = 0.055\ T^2$watt. Using the entropy of the $PrCu_6$ given by :

$$\frac{S}{nR} = \ln\left(\sinh\left(\frac{2I+1}{2I}x\right)/\sinh\frac{x}{2I}\right) - x\left(\frac{2I+1}{2I}\right)\coth\left(\frac{2I+1}{2I}x\right) - \frac{x}{2I}\coth\frac{x}{2I}$$

where $x = \frac{g_N \mu_N (1+K) B}{kT}$ and K is the enhancement factor, and using the thermodynamical relation dQ=TdS,

we can easily calculate the duration (Δt) of the isothermal demagnetization as a function of cooling power : $\Delta t = 86/\dot{Q}^{1/2}$ s. or as a function of temperature $\Delta t = 360/T$ s. So during several hours the $PrCu_6$ has a cooling power that is several magnitudes larger than that of a ^3He-^4He dilution refrigerator, which makes it very suitable as a precooling stage for nuclear demagnetization experiments.

-b) Demagnetization of In : 8 moles of In (dimensions : 80 bars of diameter 0.6 cm and length 6 cm) could be precooled by demagnetization of the $PrCu_6$ with a characteristic time (t_c) of 3 hours to 12 mK in a field of 6.3 T, while 2 moles of In in the same way could be precooled till 8 mK. After demagnetization of the In (t_c between 2 and 3 hours) we reached 0.9 mK with 8 moles of In and 0.7 mK with 2 moles of In. We stayed below 2 mK during three days with 8 moles of In, while the external heat leak in that experiment was 16 nW.

-c) Demagnetization of $PrNi_5$: on a $PrNi_5$ sample consisting of 5 bars each of 0.6 cm diameter and 6 cm length have been done two experiments. In the first place the 0.176 moles of $PrNi_5$, which was coated by a thin layer of In to improve the heat contact, was precooled by demagnetization of the $PrCu_6$ ($t_c \simeq$ 1 hour) to 11 mK. Demagnetization from a field of 6.3 T resulted in a lowest temperature of the $PrNi_5$ sample of 2.4 mK. Direct precooling of the $PrNi_5$ by the ^3He-^4He dilution refrigerator till 25 mK in a field of 6.3 T resulted in a lowest temperature 3.5 mK.

-d) Demagnetization of $PrIn_3$: A sample of 0.04 moles of $PrIn_3$ has been demagnetized after precooling by demagnetization of $PrCu_6$. The starting temperature in a field of 3.5 T was 5.7 mK, while the lowest temperature after demagnetization was 3.4 mK. Although the previously mentioned initial conditions for the demagnetizations of $PrNi_5$ and $PrIn_3$ demonstrate the feasibility of our apparatus to study possible nuclear spin ordering effects at extremely low temperatures (almost complete nuclear spin entropy removal), the final temperatures were rather disappointing. A combination of factors may be the reason for this. In the first place the heat capacity of the samples is very small both because of the small size and of the fact that the precooling increases the B/T ratio to such an extent that the peak of the Schottky curve for the specific heat is amply passed. Secondly the framework used for these measurements was suitable for the experiments on great amounts of In, but the smaller samples experience an eddy current heating, which is relatively large. These explanations are supported by the experimental observation of an increasing temperature during the first part of the demagnetization. Measurements with a changed configuration are prepared now.

-e) Nuclear orientation for ^{54}MnZn /2/ : We have done γ-ray anisotropy measurements on a very dilute sample ZnMn (Mn concentration less than 0.2 ppm). Using the "fast spin relaxation" model we were able to fit all measurements as a function of temperature between 3 mK and 50 mK and in magnetic fields between 0.065 T and 6 T (see figure 2).

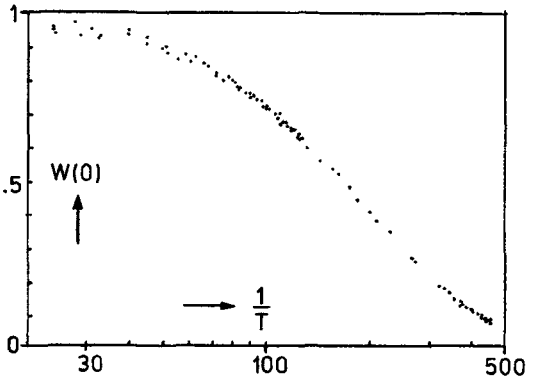

Fig. 2 : Example of anisotropy measurements on ZnMn B_{app}=0.9 T ; B_{eff}=17.4 T.

Below 0.065 T an attenuation of the anisotropy effect occurs, which could not be explained satisfactorily. The saturation value of the effective hyperfine field is determined to be 19.5 T, while the Kondo-temperature deduced from the slope of the curve of the effective hyperfine field vs. the applied field for low applied fields is determined to be 0.19 K.

-f) Nuclear orientation of ^{95}NbPt /3/ : on a sample of ^{95}Nb dissolved in a Pt-foil we have done γ-ray anisotropy measurements by brute force polarization. In the temperature region of 3 mK till 20 mK and in magnetic fields of 1 T till 6.3 T with a maximum B/T value of 800 T/K we could fit the anisotropy measurements assuming a nuclear magnetic moment of the ^{95}Nb of 6.4 μ_N.

References

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