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HEAT TRANSFER IN UNSATURATED SUPERFLUID HELIUM

G. CLAUDET*, L. SENET*

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Summary

Measurements of heat transfer were carried out in open vertical channels filled with liquid helium which was either saturated or under pressure.

The graphs illustrating the results of these measurements show that in unsaturated superfluid helium, there are two distinct heat transfer rates.

We are suggesting an interpretation of these results founded upon the existence of two critical heat fluxes.

I - INTRODUCTION -

The purpose of this study was to ascertain the suitability of using unsaturated superfluid helium as a coolant for superconducting coils. Comparative measurements of heat transfer occuring with the same sample immersed in normal helium, in either saturated or unsaturated superfluid helium, were carried out at various temperatures and pressures.

II - EXPERIMENTAL -

Figure 1 illustrates a typical coil cooling channel :

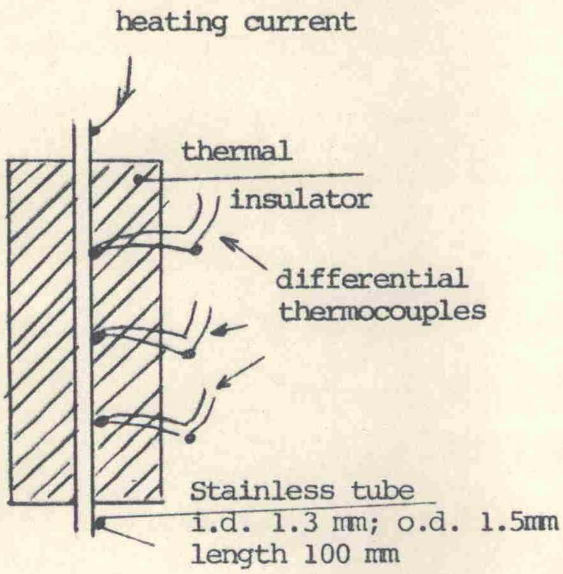

Fig. 1 : Diagram of the sample

this channel consists of a stainless steel tube, uniformly heated by an electric current of measured voltage and intensity. A thermal insulator (Stycast 2850 FT) covers the outside of the tube.
The whole assembly is immersed vertically in a helium bath for which pressure and temperature can be set independently.
Heat is evacuated through the inner heated tube, and rise in temperature with respect to the cooling bath is measured by three differential thermocouples (Au-Fe 0.3%; chromel) located outside the tube at three positions 1/4, 1/2, 3/4 of the way up.

The temperature of the inner wall of the tube is obtained by adjusting the measured result by the temperature difference calculated for the tube thickness.

We checked that heat flux through the insulator was negligible.

III - MEASUREMENTS RESULTS -

For each helium bath pressure and temperature pair, the temperature of the inner wall tube has been plotted versus the total dissipated power.

Each diagram contains three curves which correspond to the three measurements points.

When temperature oscillations occur, the two extreme values have been plotted.

III - 1. Saturated helium

- Figure 2 corresponds to a bath of normal helium at 4.2 K and 1 atmosphere. Critical flux is 500 mW, that means 0.12 W per square centimeter of heating surface, in agreement with results found by Lehongre et Al. (1) under similar conditions.

- Figure 3 was obtained with a saturated superfluid helium bath at 1.9 K and 17.6 mm Hg, the sample immersed under 20 cm.

III - 2. Unsaturated superfluid helium. Effect of pressure :

Figures 4, 5, 6, 7 and 8 were obtained at 1.85 K and under pressures varying from a few mm. Hg up to 3.5 ata.

III - 3. Unsaturated superfluid helium. Effect of temperature :

Figures 9, 10, 11, 12 and 13 correspond to superfluid baths with temperatures varying from 1.7 K to 2.1 K but under normal atmospheric pressure.

IV - DISCUSSION OF RESULTS -

All the tests carried out in unsaturated superfluid helium reveal the same characteristics :

Heat transfer occurs according to two distinct rates which lead to the definition of two critical heat fluxes in connection with two different temperature levels. For low power rate, before the first critical heat flux, heat transfer in the superfluid helium occurs without temperature gradient, therefore without mass transfer.

The results of paragraph III - 2 show that whatever the pressure applied the first critical heat flux appears near 3.7 W/cm2 (taking in account the channel cross-section) for a bath temperature of 1.85 K.

Similar results were obtained in saturated superfluid helium by Bertmann and Kitchens (2), Passow (3), Chapmann et Al (4) and unsaturated superfluid helium by Linnet and Frederking (5) and Kraft (6).

All these experimentations are made without mass transfer in capillary tubes on channels at temperature near 1.8 K - 1.9 K and the authors find critical heat fluxes of between 1 and 3 W/cm2, despite very different experimental geometries, pressures, and methods of heating (localized or distributed).

The first critical heat flux depends only on the bath temperature (cf. III-3), thereby confirming that it is a function of the density of superfluid atoms in the two-fluid model.

When the heat flux exceeds the first critical one, a temperature gradient appears in the helium filling the tube.

As the liquid temperature rises, its heat transfer capacity decreases, and it only stops heating when it has reached the boiling temperature corresponding to the pressure applied on the bath.

In such conditions, a characteristic rate stable in temperature is again reached in the heating tube through the boiling of the helium at a temperature corresponding to the applied pressure (cf. III - 2).

The two flow rates are quite distinct in experiments carried out at high pressures. However, when the over-pressure is slight, or when it is an effect of depth of immersion, as in a saturated bath, the two rates occur at temperature levels very close together, but remain even if they are difficult to distinguish.

When boiling has occured in the tube, appreciable differences in density give rise to convection movements which enable the heat flux to increase until it attains a second critical flux at which the rate of vaporisation becomes too large.

In our experiments, this second critical flux depends both on pressure and temperature (heat of vaporisation and gas density), but it is reasonable to suppose that it is greatly influenced by the experimental geometry and its effect on convection.

Neither of the two critical flux we detected increase stadily with pressurization of the bath, as was the case in Roubeau (7) experiments, which were carried out up to substantial temperature differences, and which cannot be directly compared with our experiments.

The existence of this second flux may also explain the apparently surprising results of Goodling and Irey (8), Chapman (9), Lemieux and Léonard (10), who note an important effect of the depth of immersion in saturated superfluid baths on convex geometries (cylinders, wire or planes) which allows intense convection in a low viscosity fluid.

V - CONCLUSION -

For the purpose of maintaining a superconducting system at a temperature as low as possible, it is worth while to use superfluid helium under pressure, which affords many advantages, both technological and electrical, over saturated superfluid helium. However in this case heat transfer will be limited to the first critical heat flux.

ACKNOWLEDGEMENT -

We wish to present our sincere thanks to Mr. P. Roubeau for many rewarding discussions on this subject.

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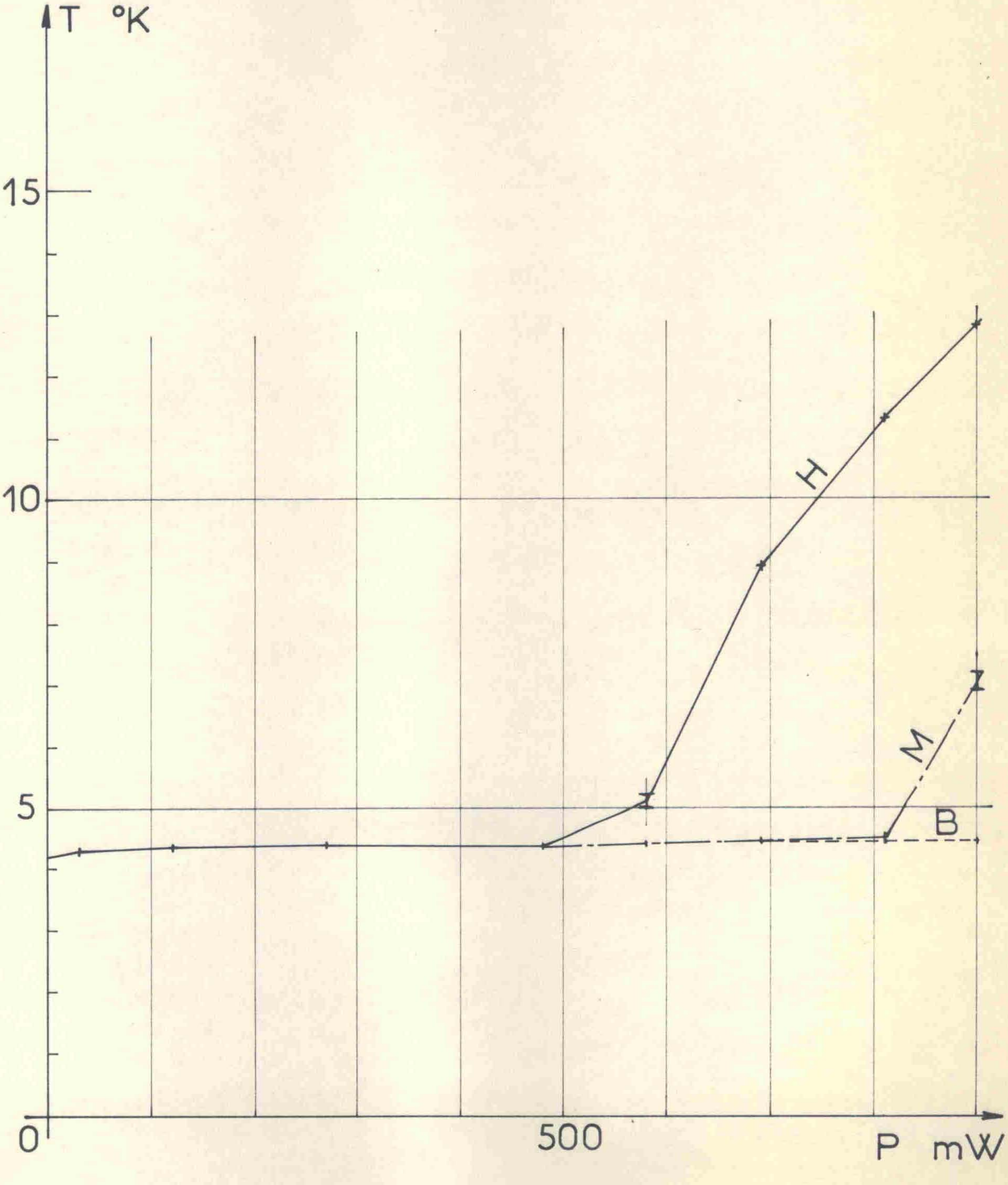

FIG.2 Normal helium T = 4.2 K ; P = 760 mm Hg
Depth of immersion : 20 cm

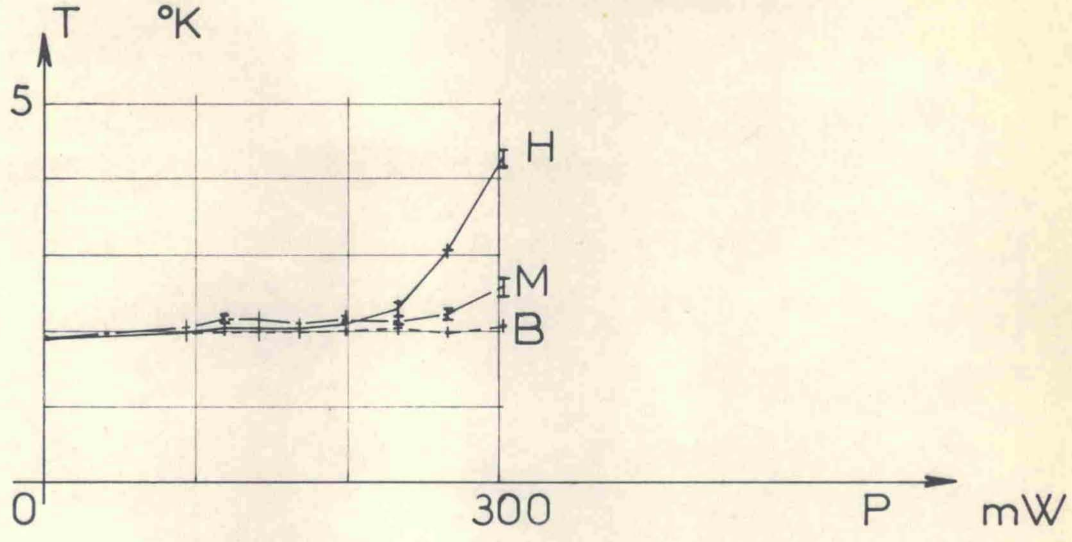

FIG. 3 : Superfluid helium T = 1.9 K; P = 17,6 mm Hg
Depth of immersion : 20 cm

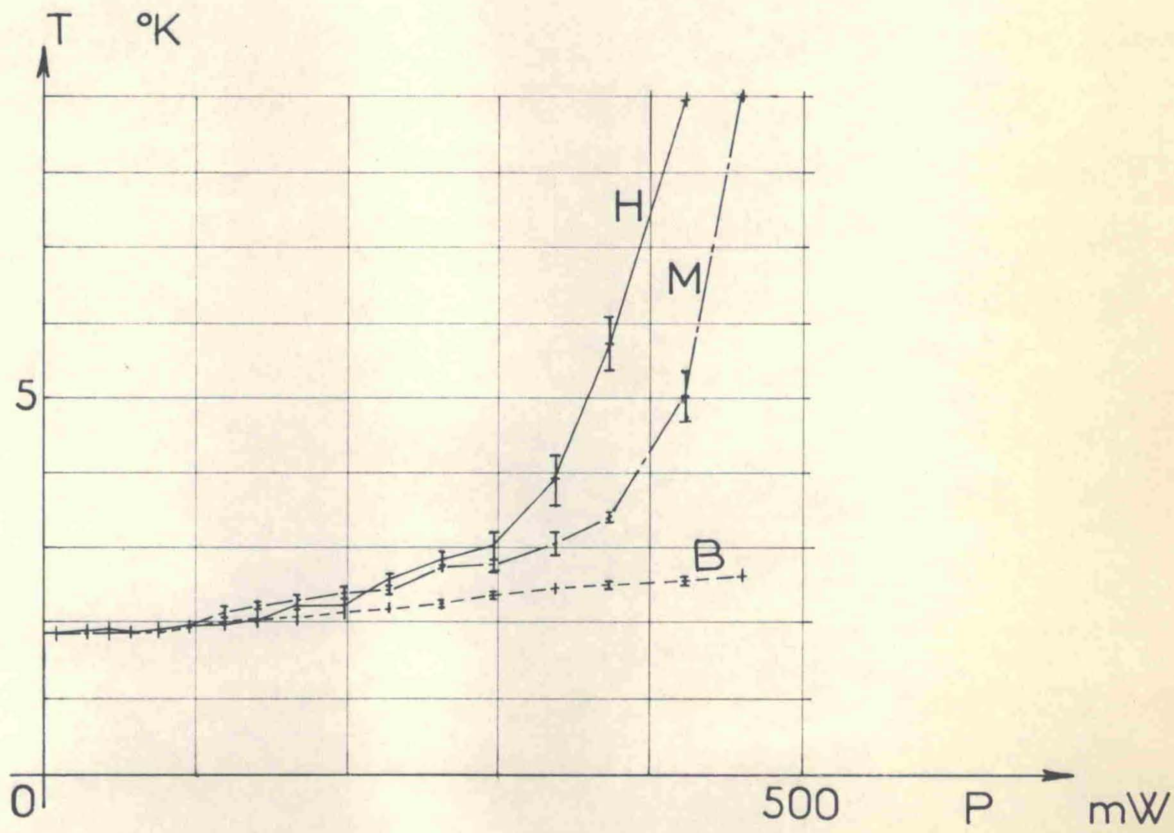

FIG. 4 : Unsaturated superfluid helium
T = 1.85 K ; P = 32,5 mm Hg

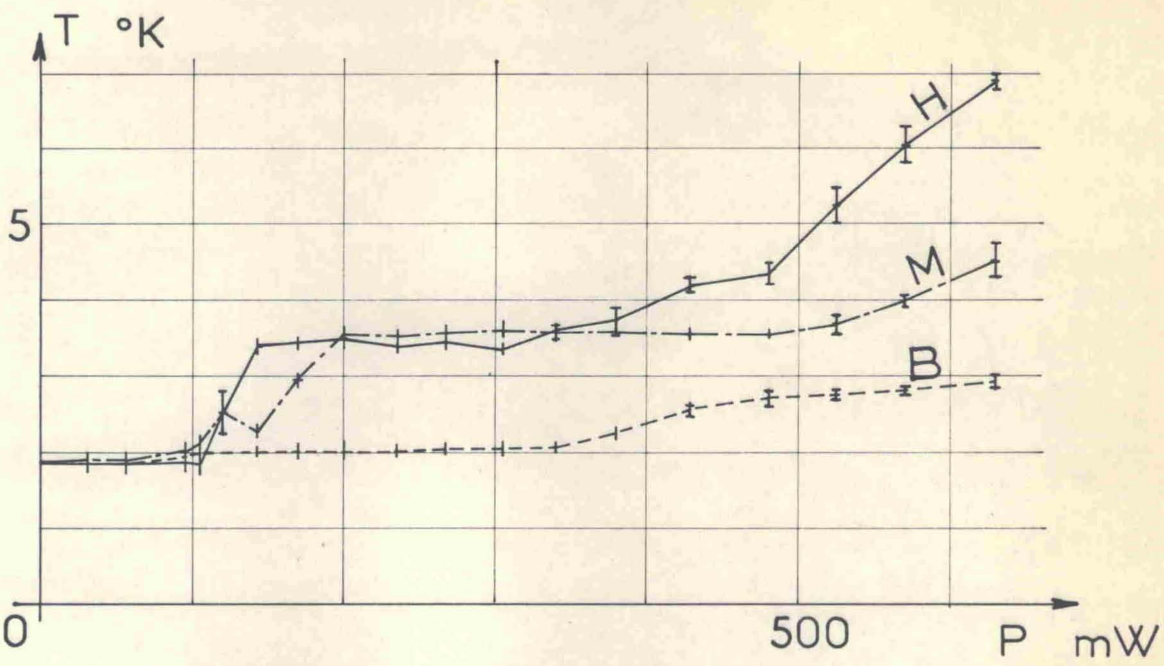

FIG. 5 : Superfluid helium T = 1.85 K; P = 335 mm Hg

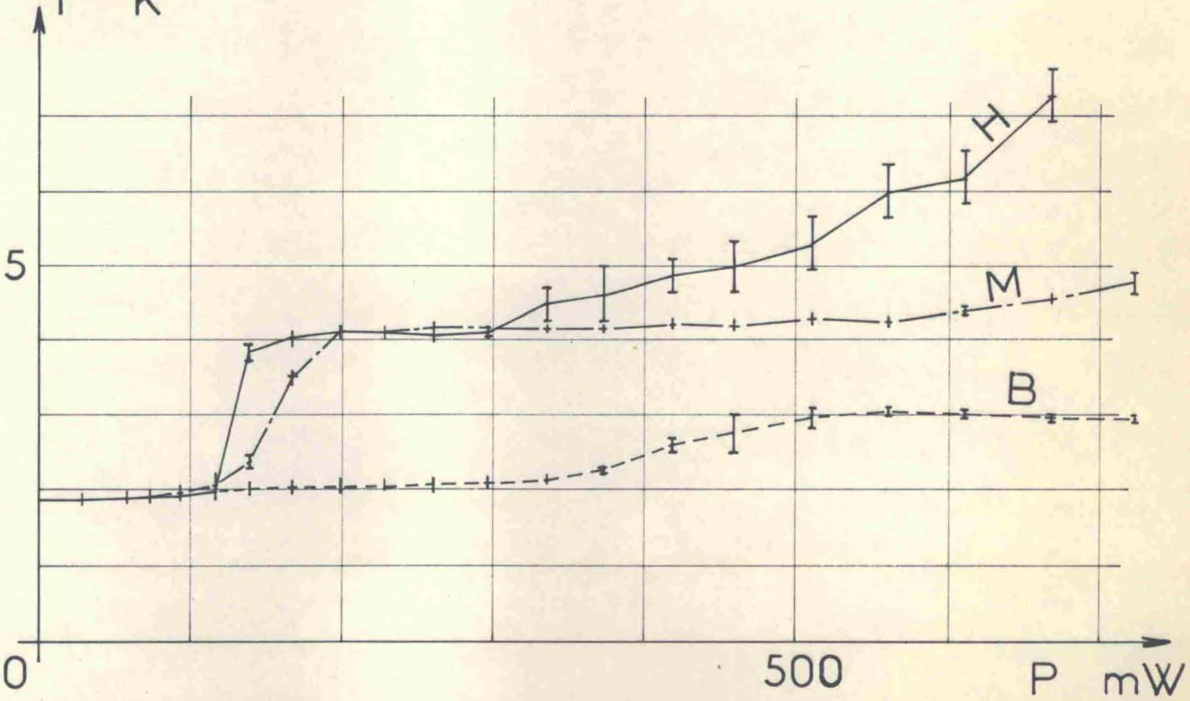

FIG.6 : Superfluid helium T = 1.85 K ; p = 1 atm

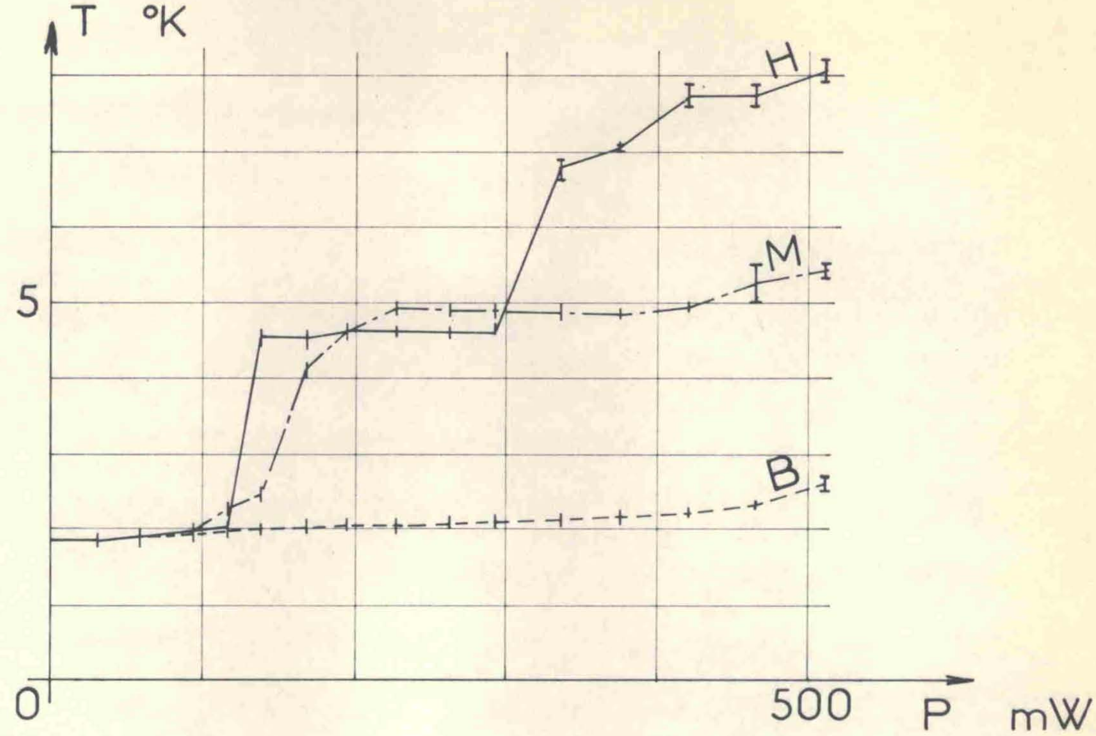

FIG.7 : Superfluid helium T = 1.85 K ; p = 2 atm

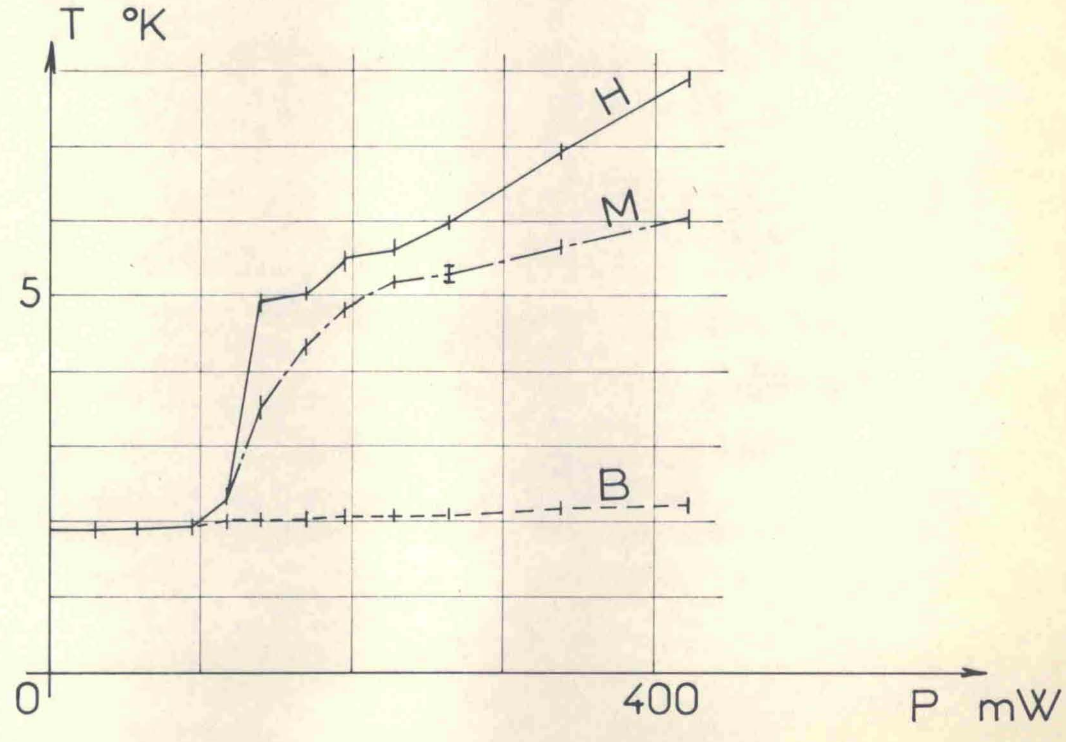

FIG.8 : Superfluid helium T = 1.85 K ; p = 3.5 atm

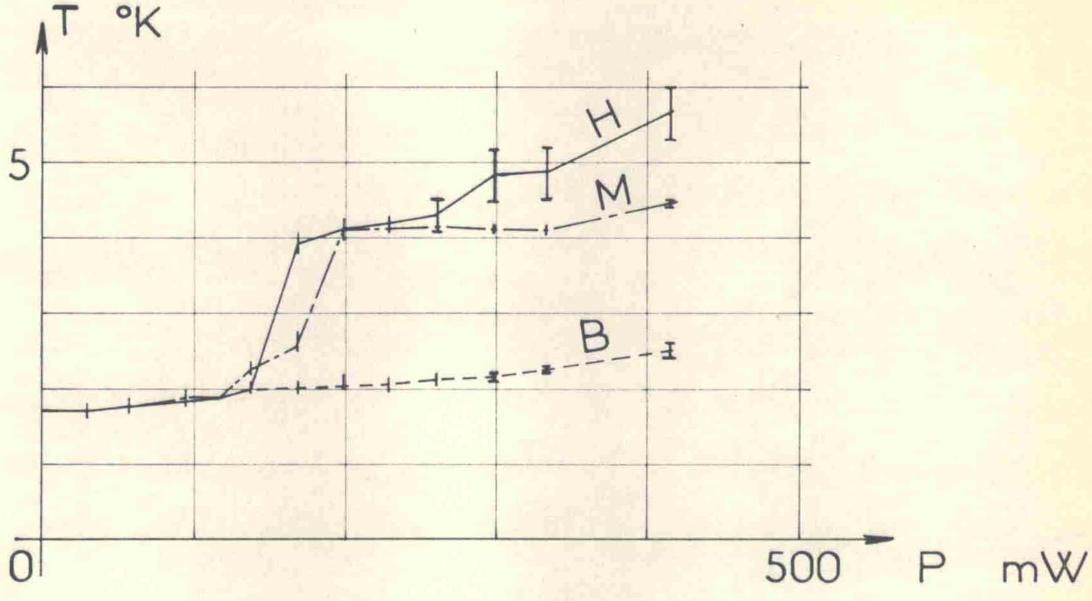

FIG.9 : Superfluid helium T = 1.7 K ; p = 1 atm

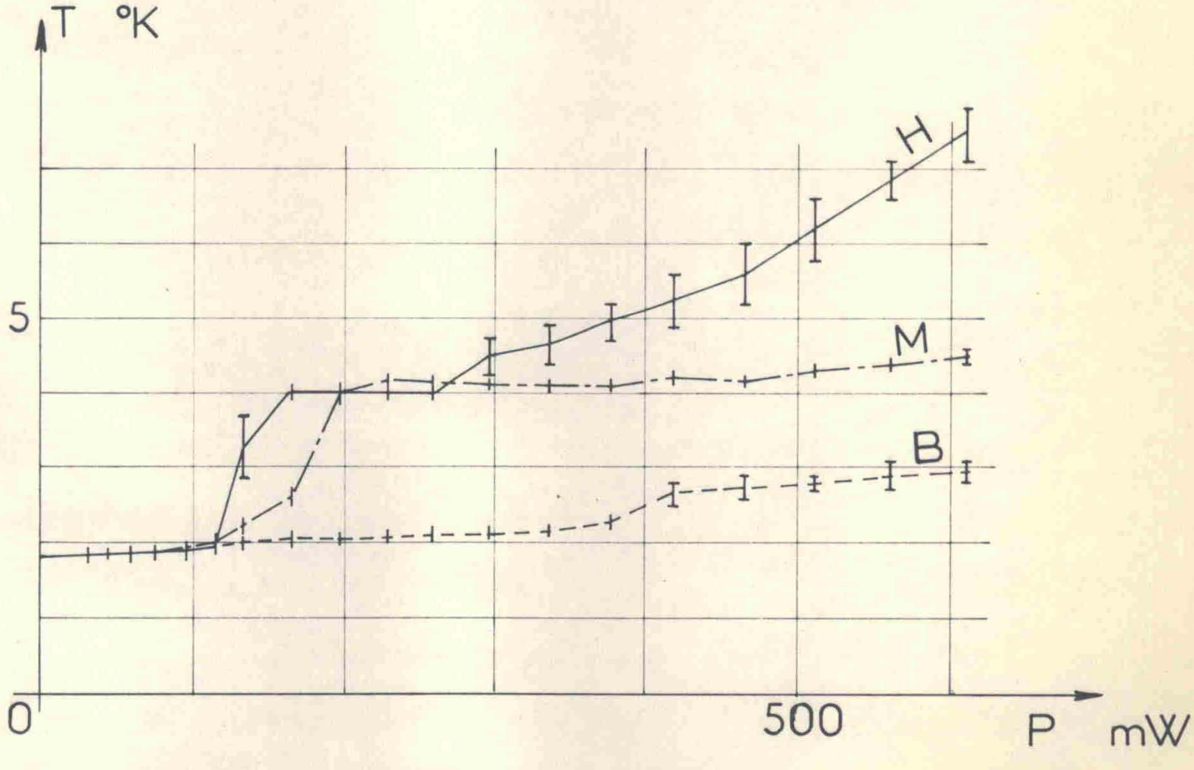

FIG.10 : Superfluid helium T = 1.8 K ; p = 1 atm

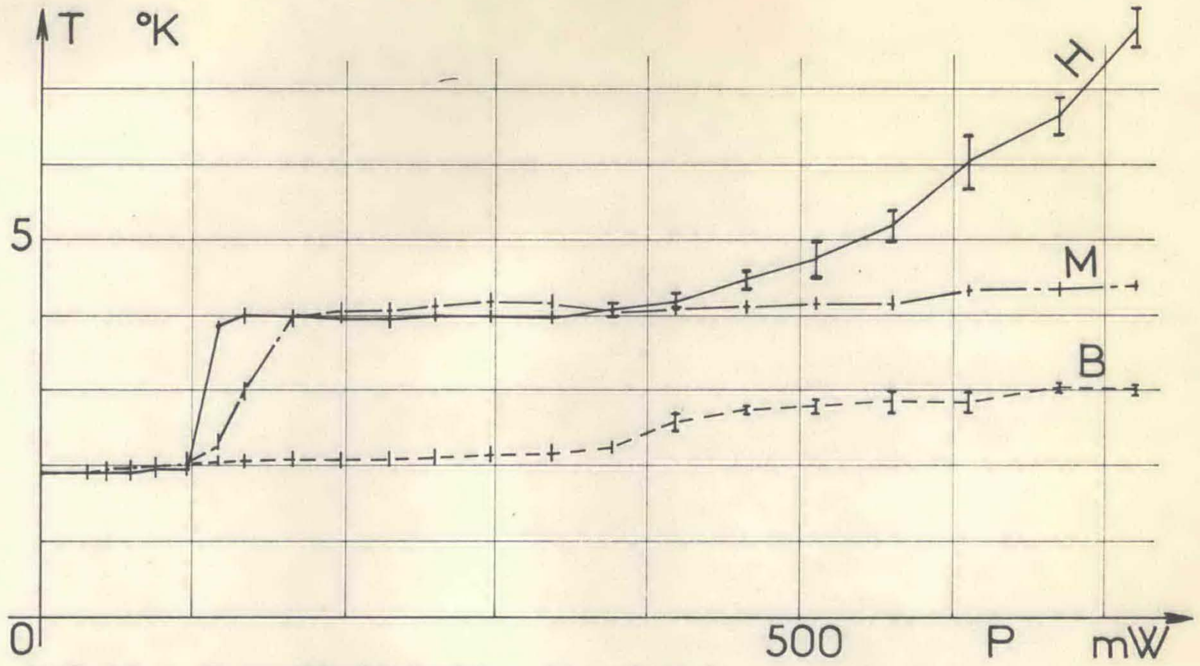

FIG.11 : Superfluid helium T = 1.9 K ; p = 1 atm

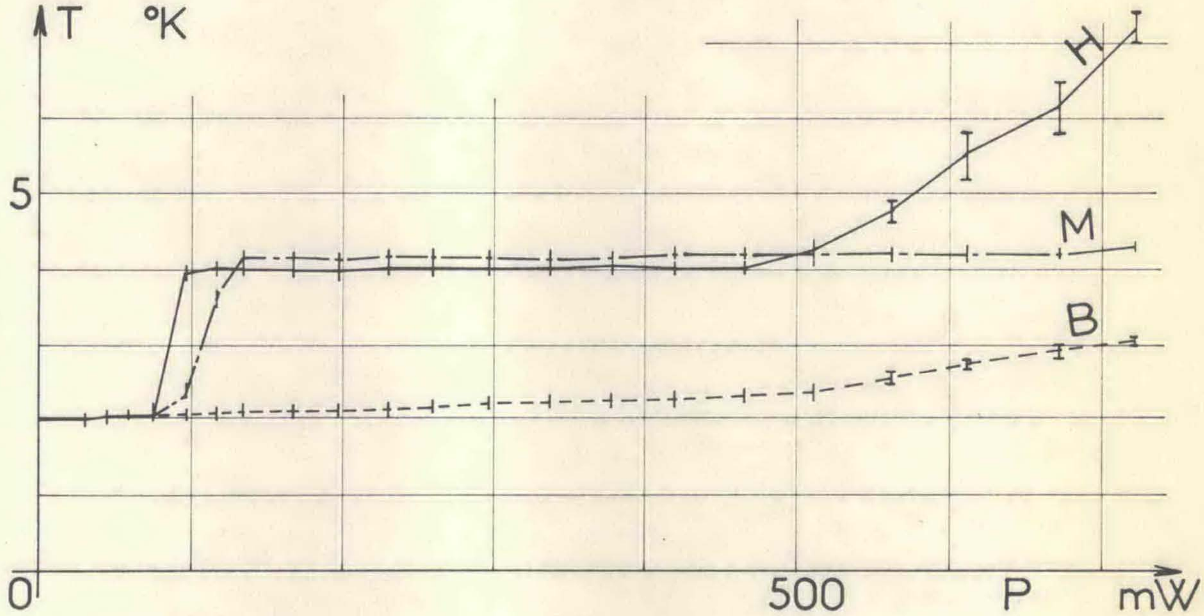

FIG.12 : Superfluid helium T = 2 K ; p = 1 atm

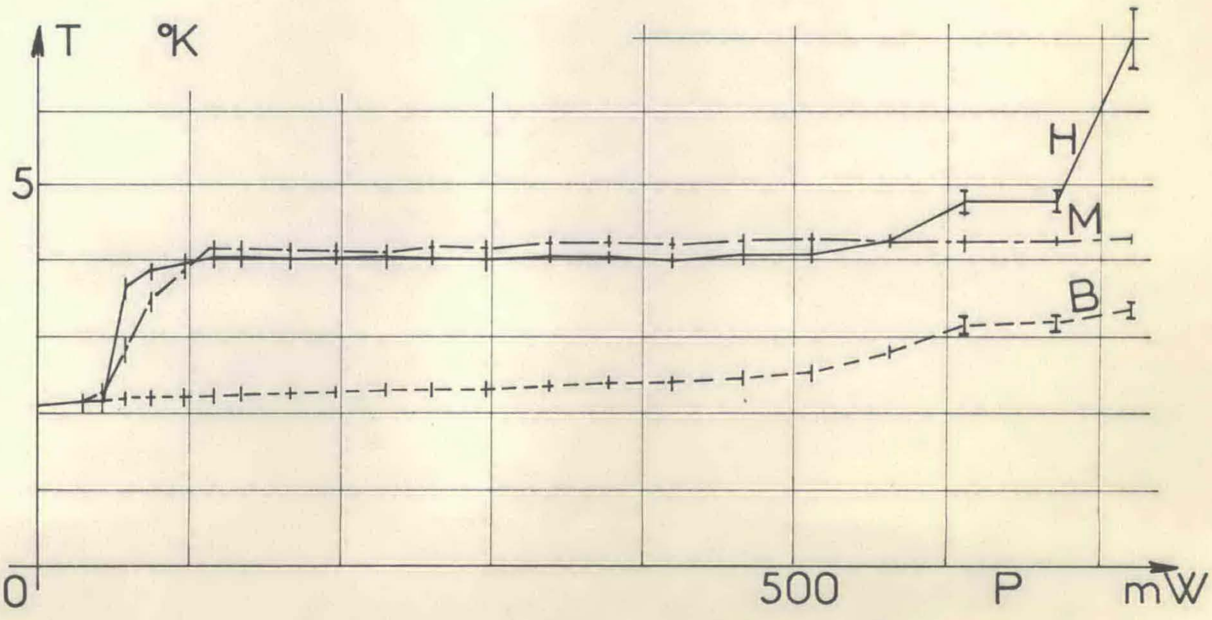

FIG.13 Superfluid helium T = 2.1 K; p = 1 atm