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METAL-INSULATOR TRANSITION IN YTTERBIUM*

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Resistance measurements have been performed with Yb under hydrostatic conditions between 1 bar and 17 kbar down to 4.2°K. It is not possible from resistance measurements alone to give an unambiguous conclusion but our results are not in disagreement with a crossing between the valence and the conduction band around 15 kbar.

PREVIOUS work has shown that metallic Yb could behave as an insulator under high pressure in the f.c.c. phase.[1,2] We will give in this letter some experimental results obtained with Yb. The main difference with the previous authors is that the work to be described now has been done with a truly hydrostatic equipment. The samples used are cut out of the bulk material. Samples B came from Research Chemical (Phoenix), and have a nominal purity of 99.9 per cent. Samples A were purified in vacuum distillation up to a 99.9 + % purity. Their resistance ratio $R(300)/R(4.2)$ are respectively 15 and 30.

The pressure apparatus, to be described in more details in the near future,[3] is essentially a pressure intensifier connected to a pressure vessel in a variable temperature cryostat via a capillary tubing. The pressure medium is either helium at $P < 13$ kbar, or a mixture 1/2 isoamyl alcohol, 1/2 pentane (4) at $P > 13$ kbar for safety considerations. Pressure is measured by a manganin gauge located in one part of the apparatus at room temperature. We checked that no sign of lack of hydrostaticity has ever been observed while using a slow cooling method.[5] The four leads method has been used for resistivity measurements with a d.c. Tinsley bridge.

Figure 1 shows the isotherms of the ratio of the resistance at 300°K and 4.2°K to the resistance R_0 at 300°K under atmospheric pressure.

As noticed in earlier experiments,[1,2] the temperature coefficient of the resistance $\partial R/\partial T$ is positive when $P < P_0$, and becomes negative when $P > P_0$.

On Fig. 2 the isobars of $\log(R/R_0)$ vs. $1/T$ for $P > P_0$ reveal two interesting features:

– at temperature lower than 8°K there is a saturation of the resistance. The exhaustion value is an exponential function of the pressure, Fig. 1;

– in the range 10–300°K, $\log(R/R_0)$ is a linear function of the temperature such as $R \propto \exp(G/2kT)$ where G is the activation energy. We checked a linear variation of G vs. pressure between 15 and 17 kbar, with $\partial G/\partial P = 30$°K/kbar.

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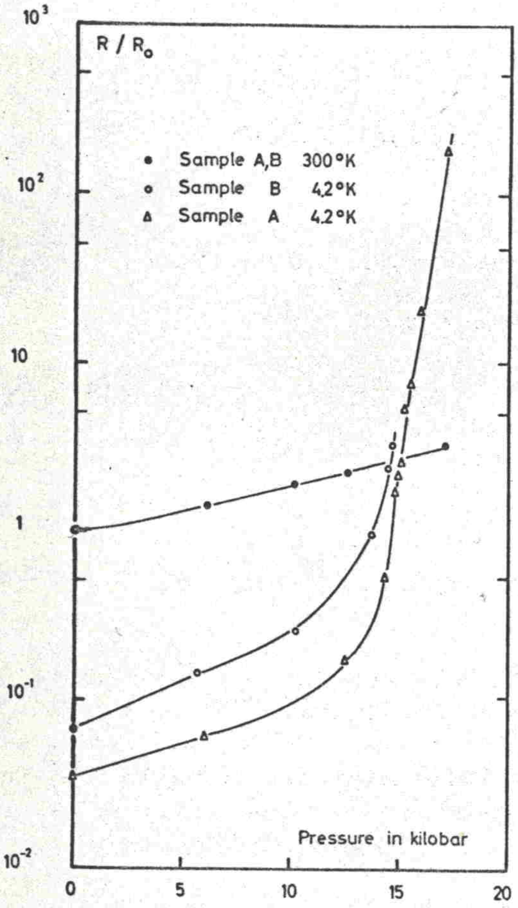

FIG. 1. Resistance vs. pressure at 300°K and 4.2°K.

Within the frame of a two bands model one may think of two possible explanations for these measurements:

(1) there is a real crossing between the top of the valence band and the bottom of the conduction band at a pressure $P = P_c$, such as for $P > P_c$, G is related to the energy gap of the insulating phase of Ytterbium and therefore $\partial R/\partial T < 0$ for $P > P_c$. The extrapolated zero G value for the pressure is $P_c = 14.80$ kbar, and then $P_0 = P_c$.

(2) However, as has been noticed by McWhan *et al.*,[1] a negative $\partial R/\partial T$ does not imply necessarily the preceeding explanation. This may occur because of a very small overlap between bands of the order of kT in a semi-metallic phase. If crossing between bands is likely to occur, this may happen at a higher pressure. The latter paragraph would explain the behaviour of bismuth under pressure.[1,6] As to Yb, we can make the two following remarks. On one hand, from Fig. 2, there is a well established exponential behaviour in a large temperature range as soon as $P > P_0$. This fact suggests that $P_c \simeq P_0$, and that for $P > P_0$ two bands with parabolic density of states $N(E)$ near the band edges are separated by a gap G. Given the small Debye temperature (118°K), even at low temperature, the carrier mobility can be dominated by the lattice. Therefore the $T^{-3/2}$ behaviour of the mobility cancels out the $T^{3/2}$ factor in the density of carriers variations versus temperature and gives the result of Fig. 2 for the resistance behaviour. On the other hand, it arises out of Fig. 1 that the 4.2°K resistance does not depend exponentially on the pressure in the whole range of pressure investigated. At low pressure it tends rather to show a small d$\log R$/dP close to the 300°K value whereas d$\log R$/dP increases rapidly

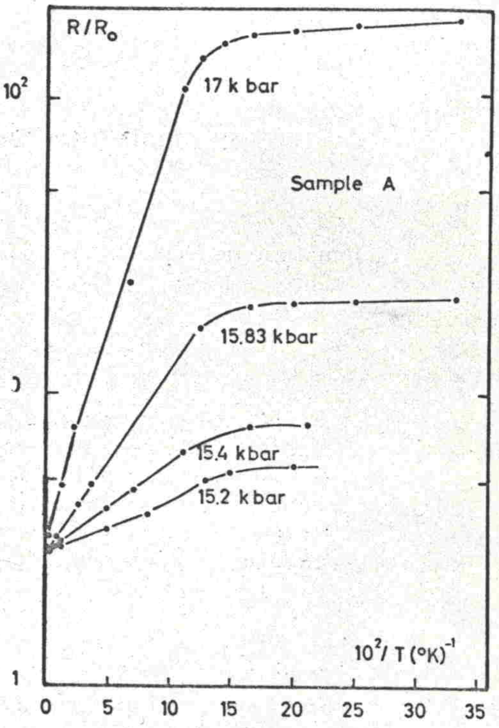

FIG. 2. Resistance vs. $1/T$ for $P > P_0$ in sample A.

around P_0 and becomes constant at higher pressures. We will assume that the resistance variation at 4.2°K is mainly due to the pressure dependence of the number of carriers. Therefore at increasing pressures $N(E_F)$ decreases. In the case of stiff band edges the decrease of $N(E_F)$ can even be very fast and give rise to a large increase in the resistance at 4.2°K when $P < P_c$ in the semi-metallic region.

The low temperature plateau of resistance for $P > P_c$ suggests that $N(E)$ is not zero at band edges but that due to the lattice defects or to the impurities there exist exponentially decreasing tails in the energy gap G.[7] Assuming a rigid bands model, the overlap between impurity bands decreases and so does the density of carriers exponentially with pressure at 4.2°K.

We saw that although it is not possible to give an unambiguous conclusion for the metal-insulator transition in Yb, the good accuracy of the measurements performed with the hydrostatic pressure equipment allows us to believe that Yb might very well be a genuine insulator at pressure higher than 15 kbar. Experiments of Hall effect and de Haas–Van Alphen effect under pressure are now in progress in our laboratory.

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Des mesures de résistance ont été faites sur l'Ytterbium dans les conditions de pression hydrostatique entre 1 bar et 17 kbar jusqu'à 4.2°K. Sans pouvoir tirer de conclusions définitives des mesures de résistance, on peut simplement dire que ces résultats ne sont pas en désaccord avec un croisement possible de la bande de valence avec la bande de conduction vers 15 kbar.