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ELECTRICAL RESISTIVITY ANOMALIES IN THE LINEAR COMPOUND NbSe$_3$ DOWN TO 7 mK

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Abstract.- We report on detailed resistivity measurements of the linear compound NbSe$_3$ down to 7 mK. Two drops in resistivity occur at 2.2 K and 0.4 K indicating two new transitions. Strongly non-linear effects are observed below 2.2 K. We suggest to associate these transitions with the CDW's which appear in this compound at 145 K and 59 K.

The 1 D transition-metal trichalcogenide NbSe$_3$ has very recently arisen a large interest on account of its remarkable properties. Two phase transitions occur at $T_1 = 145$ K and $T_2 = 59$ K where the resistivity shows a sharp increase /1,2/. These anomalies were ascribed to the formation of charge density waves (CDW's). Direct evidences for the formation of CDW's by electron diffraction and X-ray scattering measurements indicate that two independent incommensurate CDW's coexist in NbSe$_3$ below 50 K /3,5/. The resistive anomalies associated with the CDW's are strongly non-linear with the applied current /6/ and drastically suppressed by a microwave field /7/. These results have been interpreted by Bardeen/8/ as the evidence of the Fröhlich conductivity from moving CDW's. Magnetization measurements down to 50 mK have shown no trace of superconductivity but NbSe$_3$ becomes a bulk superconductor under pressure with a variation of the critical temperature pressure of 0.6 K/kbar /9/. We also reported that the resistivity of NbSe$_3$ drops below 2.2 K by 30 to 75 % of its residual value at 4.2 K and reaches a plateau near near 1.5 K /10/. The resistivity below 2.2 K was shown to be strongly non-linear for current densities higher than $10^{-3}$ A/mm. The measurements reported here were performed in the mixing chamber of a dilution refrigerator down to 7 mK using a four wire low frequency a.c. method. Figure 1 shows the temperature variation of the resistivity for several current densities of a NbSe$_3$ sample labelled A, a bundle of threads with a resistance ratio of 80 between 300 K and 4.2 K, whose resistivity temperature variation between 4.2 K and 1.2 K was published previously (figure 4 of reference /10/).

![Figure 1](http://dx.doi.org/10.1051/jphyscol:19786313)
quid or gaseous helium give identical result.

Fig. 2: Semi-log plot of the resistance of sample A vs. the current density, at different temperatures. From 1 to 9, \( T(K) = 2.09; 1.99; 1.90; 1.81; 1.60; 1.24; 0.697; 0.206; 0.042 \).

Figure 2 shows the resistivity as a function of the current density \( j \) for different temperatures.

Fig. 3: Resistance of two NbSe\(_3\) monocrystals vs. \( T \) for the low current density limit \((j < 10^{-3} \text{ A/mm}^2)\). Lower curve: sample B \((R_{300}/R_{4.2} = 30)\). Upper curve: sample C \((R_{300}/R_{4.2} = 7)\).

In figure 3, we present the resistivity variation for two other samples, B and C in the low current density limit \((j < 10^{-3} \text{ A/mm}^2)\). These samples were monocrystals and their typical dimensions were \( 5 \times 0.05 \times 0.01 \text{ mm}^3 \). Both ends of the samples were glued with silver paint on sintered silver to improve the thermal coupling between the sample and the helium bath. The lower part of figure 3 is the variation of sample B, which has a resistance ratio of 30. The drop below 2.2 K is only 35% but we observe a second drop below 0.4 K as for sample A. However the residual resistance at 7 mK is very different from zero. The upper part of figure 3 is for sample C which has a resistance ratio of 7. The drop below 2.2 K is very broad and the second drop is wiped out.

The non-linear properties below 2.2 K and the absence of increase of the diamagnetic (less than \( 10^{-3} \) of the volume) down to 50 mK in fields as low as 1 Oe preclude any description of NbSe\(_3\) as a bulk superconductor. We previously discussed that superconducting filaments could explain the results /10/. Filaments in NbSe\(_3\) may have a morphological origin. On the other hand we have observed large Shubnikov-de Hass oscillations in relatively low fields /11/ which indicate that NbSe\(_3\) is a rather homogeneous material. However, the two low temperature transitions may be associated with the high temperature ones at \( T_1 = 145 \text{ K} \) and \( T_2 = 59 \text{ K} \), where CDW's develop in the crystals. Electron diffraction patterns reveal superlattice spots below the \( T_1 \) transition which indicate a 3D ordering between the CDW's induced on each chain /3,4/. Filaments can be seen as domains where the CDW's have a coherence of phase. By some mechanism at low temperature the CDW's in each filament may carry a current (Fruhlich mode), which explains the drop to a lower resistivity at 2.2 K and 0.4 K. The diameter of these filaments must be small compared to the London penetration depth \( \lambda \) to give no Meissner effect. Under pressure the transverse coherence length increases, thus increasing the size of the filaments and bulk superconductivity is observed (susceptibility of \(- \frac{1}{V} \) when the pressure is higher than 2 or 3 kbars /9/).

Several difficulties obviously exist in the framework of this interpretation which should only be considered a putative one. Nevertheless, any further discussion on the properties of NbSe\(_3\) must take into account the occurrence of the two low temperature transitions that we have observed.

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/8/ Bardeen, J. to be published.

