

DYNAMICAL INTERACTION BETWEEN BOTH CDWs IN NbSe<sub>3</sub>

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## ABSTRACT

We report measurements of the upper threshold field of NbSe<sub>3</sub> under pressure in the temperature range 25 K - 120 K. At the temperature of the second transition  $T_2$ , which is pressure dependent, the threshold field of the first CDW strongly decreases, which is interpreted as a dynamical interaction between the two CDWs.

NbSe<sub>3</sub> is a well-known compound undergoing two independent charge density wave (CDW) transitions at  $T_1$  (145 K) and  $T_2$  (59 K) [1,2].

Previous measurements made on the variation of the first threshold field  $E_{c1}$  versus temperature seemed to indicate a saturation at low temperature ; an other group [3] nevertheless reported different temperature behaviour for  $E_{c1}$ . To study the divergence of  $E_{c2}$  near  $T_2$  we have performed [4] experiments of  $E_{c2}$  and  $E_{c1}$  close to  $T_2$ . We have reported that in the temperature range where fluctuations can be observed near  $T_2$ ,  $E_{c1}$  decreases slowly before reaching a constant value ; but at this time no data have been recorded below 45 K.

The variation of  $E_{c1}$  near  $T_2$  could be correlated either with the absolute value of the temperature or with the absolute value of  $T_2$ . To distinguish between these two possibilities we decide to apply pressure in order to change  $T_2$ .

Here we report careful four terminal measurements of the threshold field  $E_{c1}$  under pressure ( $P < 8$  kbar) in the temperature range 25 K - 120 K. The determination of  $E_{c1}$  is made by the measurement of the differential resistance  $\frac{dV}{dI}$  ; at low temperature this method becomes less and less accurate, so we determine  $E_{c1}$  from broad band noise measurements [Fig. 1]. Nevertheless due to heating problems our range of temperature is limited at 25 K.

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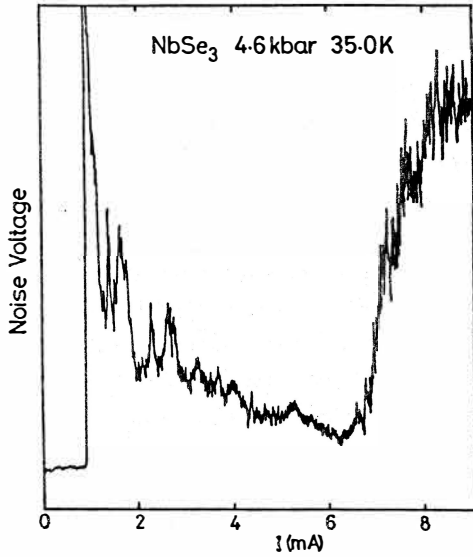


Fig. 1 - Broad band noise as a function of the dc current at 4.6 kbar and 35 K. The two sharp increases allow the determination of  $E_{C1}$  and  $E_{C2}$ .

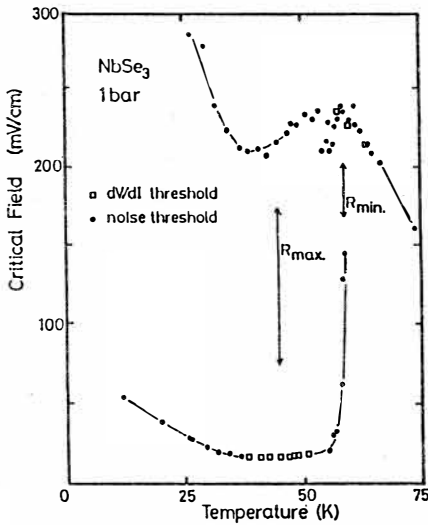


Fig. 2 - Temperature dependence of  $E_{C1}$  and  $E_{C2}$  at normal pressure.  $R_{min}$  and  $R_{max}$  corresponds to the temperature where the resistance is minimum and maximum near  $T_2$ .

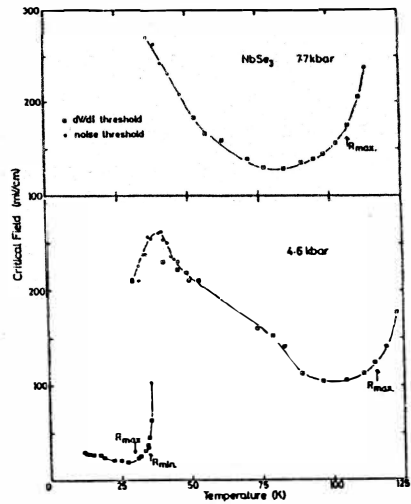


Fig. 3 - Temperature dependence of  $E_{C1}$  at two pressures and  $E_{C2}$  at 4.6 kbar.

The crystals were mounted on an araldite disc in a beryllium-copper clamp capable of retaining pressures up to 11 kbar at 300 K, resulting in about 7.5 kbar at 4.2 K. Pressures were measured at room temperature and nitrogen temperature with a pressure cycled manganin resistance located near the sample. The fluid used was an isopentane-methyl 2-pentane mixture. A loss of between 3 and 4 kbar was measured between the pressure at room temperature and that at nitrogen temperature. The resistance of the sample was measured by four probes.

For these preliminary measurements we have applied only three different pressures (1 bar, 4.6 kbar, 7.7 kbar). The amplitude of the variation of  $T_1$  and  $T_2$  with pressure is in agreement with previous measurements [5]. In Figures 2 and 3 we have drawn the variation of  $E_{c1}$  with temperature for three different pressures. At 1 bar we can observe in the Figure 2 the similar kind of temperature dependence for  $E_{c1}$  as in previous measurements [4], but for  $T$  less than 30 K,  $E_{c1}$  still increases. When the pressure is applied, the maximum in  $E_{c1}$  follows the decrease in  $T_2$  (Fig. 3) and when the second transition is suppressed, for  $P = 7.7$  kbar (Fig. 3), the maximum in  $E_{c1}$  disappears. The strong correlation between the maximum in  $E_{c1}$  and the formation of the second CDW at  $T_2$  suggests the existence of a dynamical interaction between the two CDWs. Such a decrease in threshold field has been observed in orthorhombic  $TaS_3$  around  $T = 130$  K which is the temperature where the longitudinal component of the distortion vector locks to a commensurate value. This effect has been explained in terms of a coupling between CDWs in two different types of chains. In  $NbSe_3$  two independent CDWs appear on different types of chains ; a possible locking between the two CDWs has been considered when it was noted that twice the sum of both wave vectors is in the vicinity of a lattice reciprocal wave vector [6,7]. The phase locking described by a fourth-order term in the CDW amplitudes may lead to a very small perturbation such a small gap enhancement at  $T_2$ . Fleming clearly demonstrated that  $q_1 + q_2$  is not a commensurate value [8]. Moreover, recent careful measurements of the temperature dependence of  $q_1$  with a synchrotron X-ray source has detected no variation of  $q_1$  at  $T_2$  [9]. All these measurements seem to rule out any kind of static interaction between the two CDWs at  $T_2$ . Up to now no accurate measurements of  $q_1$  and  $q_2$  have been made under electric field. We notice on Figure 2 that the decrease of  $E_{c1}$  takes place between  $T_2$  and  $T_M$ , where  $T_M$  is the temperature of the maximum of resistance. In this temperature range where the gap of the second transition begins to open, we expect a rather important back flow of normal electrons which at a second order could affect the viscosity and the critical field of the first transition ; in that case we would have a dynamical interaction between the two CDWs.

Maki [10,11], incorporating the thermal fluctuations of the phase of CDW order parameter into the Fukuyama-Lee-Rice theory, has calculated the temperature dependence of the threshold field at low temperature (e.g.  $T < \frac{T_c}{2}$ ). In the strong pinning limit the threshold field is given by :

$$E_T^S(T) = E_T^S(0) e^{-T/T_0} \frac{\Delta(T)}{\Delta(0)} \frac{\rho}{\rho_S(T)} \quad (1)$$

where  $\Delta(T)$  and  $\rho_S(T)$  are respectively the temperature dependent order parameter and condensate density, and  $T_0$  is a parameter proportional to  $\xi = v_F/T_c$ . The equation (1) predicts a minimum in  $E_T$  at  $T = T_c - \frac{T_0}{2}$  if  $T_0 \ll T_c$  and a thermal activated behaviour in the low temperature range.

In the weak pinning regime the calculation of Maki gives :

$$E_T^W(T) = E_T^W(0) \left[ \frac{E_T^S(T)}{E_T^S(0)} \right]^{4-D}$$

where  $D$  is the dimensionality of the CDW.

The Maki's theory can also describe the pressure dependence of the threshold field [10]. In the hypothesis where the most important effect of the applied pressure is to reduce the anisotropy in the Fermi velocities  $\eta$  along the crystallographic axis, so  $\eta$  increases with pressure this implies that  $E_T$  decreases like  $\eta^{-2}$  in the weak pinning regime while  $T_0$  increases like  $\eta^2$  (in the weak and strong pinning regime).

The analysis of our data at the first transition gives for  $T_0$  the value of 82 K and 50 K, respectively for pressures of 4.6 kbar and 7.7 kbar. For the second transition  $T_0$  was at 1 bar 18 K and 33 K at 4.6 kbar. The discrepancy in the sense of variation of  $T_0$  with pressure between the first and the second transition could result from different variation of  $\eta$  with the pressure. A recent analysis of previous data have shown that for the second transition  $T_0$  is close to 10 K so the high value of 18 K observed at normal pressure in the present experiments is perhaps due to the unreleased pressure.

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