electrodes separated by a thin insulating barrier can reproduce to some extent the energy dependence of the density of states in the vicinity of the Fermi level of the electrodes. This technique is largely used to derive quantities such as energy gaps in the quasi-particle density of states if one or both electrodes are superconductors. Schottky-type electron tunnelling using N-doped evaporated GaSb on $(TMTSF)_2PF_6$ or $(TMTSF)_2ClO_4$ performed under 11 kbar and ambient pressure for the two organic compounds respectively, supports the existence of a depression of $N(E_F)$ in the organic superconductor over an energy width $2\Delta \approx 3.6$ meV centred at the Fermi energy (Fig. 6a). The FIR reflectance of $(TMTSF)_2ClO_4$ studied at helium temperature reveals a drop of 5% around 3.8 meV. As shown by magneto-absorption experiments (Fig. 6b), this optical absorption threshold can be observed without significant shift of its energy up to 15 K or so. The vanishing of the absorption threshold occurs between 20 and 50 K [5]).

The experimental results presented in this section suggest the existence of a pseudo-gap of width 3.6 - 3.8 meV at the Fermi level. This pseudo-gap is suppressed by a large magnetic field and remains visible up to temperatures which are about ten times the temperature for the onset of long range superconducting order. Since organic conductors are Q-1-D conductors, precursor signs of the low temperature instabilities are expected to occur at temperatures larger than the 3-D ordering temperature. Thus, we must consider precursor effects of two different kinds: SDW or superconductivity.

We may rule out the SDW origin of the pseudo-gap for several reasons (i) no sign of magnetism has been detected (via NMR experiments) up to the temperature domain in which the pseudo-gap is observed; (ii) whenever a SDW gap is observed, it is stabilized and not suppressed by a magnetic field; (iii) there is no SDW state stable at low temperature in $(TMTSF)_2PF_6$ under pressure; (iv) electron tunnelling characteristics related to an SDW gap which have been observed in $(TMTSF)_2PF_6$ below 12 K at ambient pressure do not show the typical resistance minima on both sides of the zero bias; (v) commensurability would prevent the fluctuating SDW from contributing to the DC conduction.

Superconducting Fluctuations and Conclusion

The discussion in the previous section shows that superconductivity probably originates from the strongly developed precursor regime. However, how can one reconcile a precursor domain extending about 30 K, with a superconducting transition which behaves very much like phase transition within the mean-field theory (Fig. 3). The small critical width of the superconducting transition seen by specific heat ($\Delta T/T_c \leq 10\%$) does not support the existence of fluctuations up to $T \approx 10\ T_c$ unless the point of view of phase transitions in Q-1-D conductors is taken. In this case for a two degrees of freedom order parameter (amplitude and phase) some decoupling of the two components occurs at $T >> T_c$. The spatial correlation function of the order parameter is given by:

$$< \Delta\,(x)\,\Delta\,(0) = |\Delta|^2 \exp\left(-x\,/\,\xi\,(T)\right)$$

where $\xi(T) \approx \alpha_{//}/kT$. Consequently, at $T > 0$, the short range order which arises with a coherence length $\xi(T)$, digs a pseudo-gap of width $2\Delta \approx \alpha_{//}$ at the Fermi level. The amplitude of the order parameter reaches a significant value ($\approx \alpha_{//}$) already below the 1-D mean-field temperature, $T_1 \approx \alpha_{//}$, whereas the phase is still free to take any value until T_c is reached. At T_c inter-chain locking of the phases occurs. If the zero point motion of the phase (quantum fluctuations) is taken into account a true gap develops below T_c. Its value at $T = 0$ amounts to a real gap $2\Delta(T=0) = 3.5\ T_c$, a value much smaller than the amplitude of the pseudo-gap. For strong quantum fluctuations Schulz and Bourbonnais [6]) have derived $2\Delta(T=0) = 3.5\ T_c$; i.e. the mean-field behaviour is recovered for the phase locking transition (onset of 3-D order). Furthermore with reasonable values of the intrachain coupling ($g_1 - 2g_2 \approx 0.6$) and of the band structure anisotropy ($t_{//}/t_{\perp} = 10$), the same authors have calculated, using $T_c = 1.2$ K, that the superconducting precursor region will extend up to about 30 K.

In conclusion, organic superconductors of the $(TMTSF)_2X$ series exhibit several characteristic features of quasi-1-D electron gas and, in addition, a narrow 3-D ordering transition satisfying approximately mean-field rules is observed. Superconductivity of organic conductors is, very likely, not at its optimum in the $(TMTSF)_2X$ series. It may be possible to take advantage of the strong 1-D divergence at higher temperature and an increase of the interchain coupling could therefore allow a substantial increase of the critical temperature.

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Printed by: Pfirter frères SA
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